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Journal

of

THE ROYAL AERONAUTICAL SOCIETY

SEPTEMBER 1957

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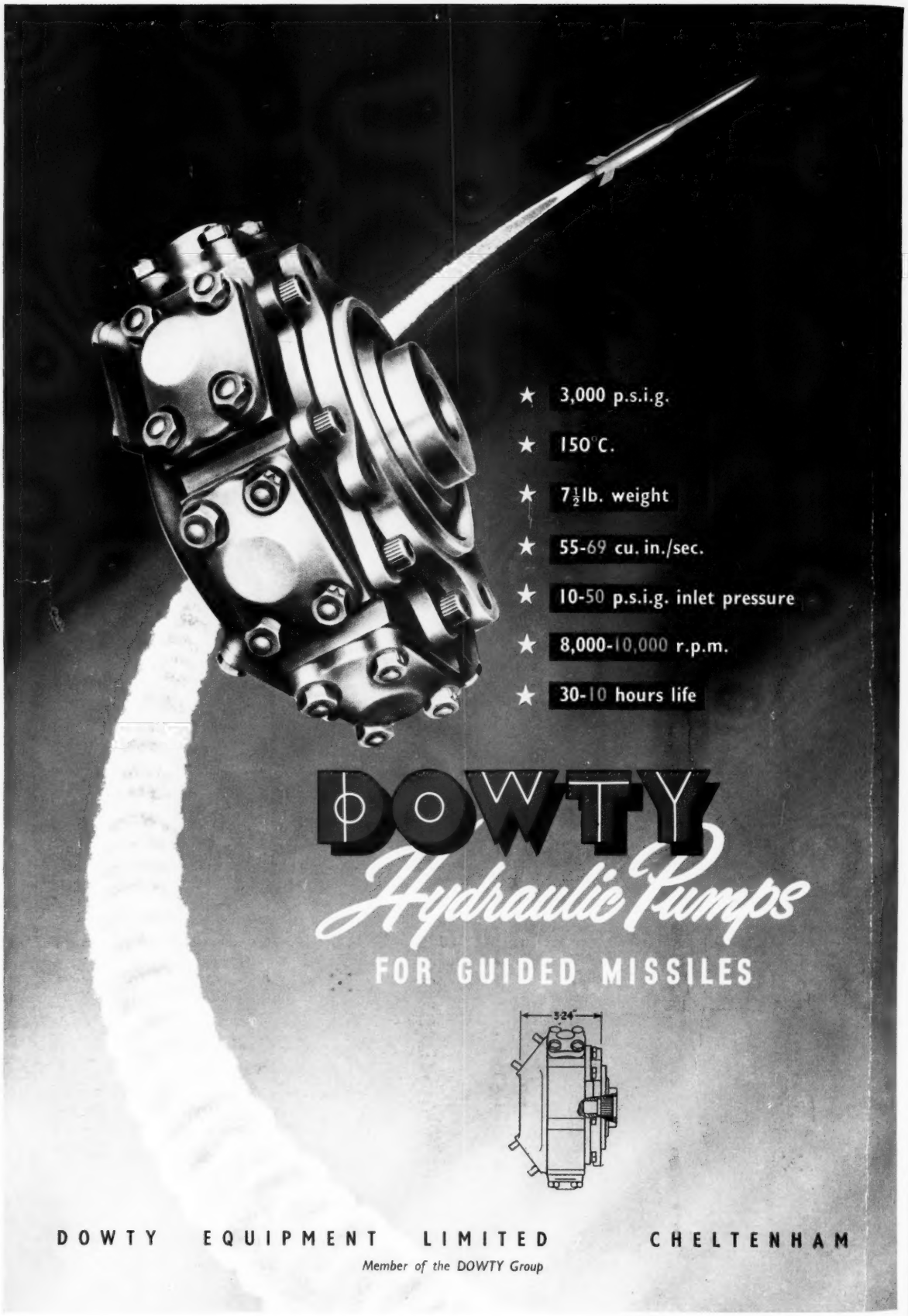
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NOTICES

45TH WILBUR WRIGHT MEMORIAL LECTURE
13th September 1957

The 45th Wilbur Wright Memorial Lecture will be given on Friday, 13th September by Dr. Clark B. Millikan on "Advanced Education and Academic Research in Aeronautics" at the Institution of Civil Engineers, Great George Street, London, S.W.1, at 6 p.m. (Tea at 5.30 p.m.)

DIARY

9th-12th September 1957
Sixth Anglo-American Aeronautical Conference—Folkestone, Hotel Metropole.

13th September
45th Wilbur Wright Memorial Lecture "Advanced Education and Academic Research in Aeronautics." Dr. Clark B. Millikan. At the Institution of Civil Engineers, Great George St., S.W.1, at 6 p.m. (Tea 5.30 p.m.)

15th September
Garden Party, Wisley Aerodrome. 2.30-5.30 p.m.

GRADUATES' AND STUDENTS' SECTION

26th September
The Future of the Royal Air Force. Charles Orr-Ewing

16th October
Trends in Air Transport. P. W. Brooks. In the Library, 4 Hamilton Place, W.1. 7.30 p.m.

BRANCHES

24th September
Luton.—Flight Testing the Vulcan. R. J. Falk. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.

8th October
Luton.—Human Limitations of High Performance Flight. Sqn./Ldr. T. C. D. Whiteside. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.
SECTION LECTURE.—Some Thoughts on Non-Linear Problems in Aerodynamics. P. J. Duncton. In the Library, 4 Hamilton Place, W.1. 7 p.m.

17th October
The Thirteenth British Commonwealth Lecture.—Why Airlines are Hard to Please. B. S. Shenstone. At the Institution of Mechanical Engineers, Birdcage Walk, S.W.1, 6 p.m. (Tea at 5.30 p.m.)

22nd October
SECTION LECTURE.—Aircraft Instrumentation for Flight Test Purposes. R. R. Duddy and I. McLaren. In the Library, 4 Hamilton Place, W.1. 7 p.m.

KING GEORGE VI MEMORIAL FELLOWSHIPS

A number of King George VI Memorial Fellowships, which are sponsored by the English-Speaking Union of the United States, are again being offered to British students to enable them to continue their scientific and technical education in American institutions. For the academic year 1958-59 a number of Fellowships will be awarded in two categories to graduates of British universities who wish to take post-graduate courses at American universities and, to students of British technical colleges who wish to take courses at similar institutions in the U.S.A.

Candidates must be citizens of Great Britian or Northern Ireland, either by birth or by naturalisation; must hold a British university degree, or be candidates for such a degree in the summer of 1958; *or* must hold a Higher National Certificate, or be a candidate for such a certificate in the summer of 1958. They must be not less than 18 nor more than 30 years old on 31st August 1958 and be unmarried.

Application forms, which must be returned not later than 16*th November* 1957, may be obtained from the Secretary of the British Selection Committee, Mrs. D. R. Dalton, B.A., King George VI Memorial Fellowships Committee, 37 Charles Street, Berkeley Square, London, W.1.

GARDEN PARTY, WISLEY AERODROME
15th September 1957

Members who have not already applied for their tickets for the Garden Party should do so at once. Tickets which include tea, are 10s. 6d. each and 5s. 6d. for children between the ages of 5-15 years.

When applying for tickets will members please state whether they are travelling by road, rail or air so that particulars of travelling arrangements can be sent to them. Special buses will leave Weybridge Station at one o'clock and two o'clock to meet trains and will return to the station after the Garden Party. Members wanting seats on the buses should state the number they require and whether they wish to use the one o'clock or two o'clock bus.

TRAINING CENTER FOR EXPERIMENTAL AERODYNAMICS (T.C.E.A.)

Applications for the second class for studies in experimental aerodynamics, which starts on 1st October 1957, are now being accepted by the Training Center for Experimental Aerodynamics in Belgium. The T.C.E.A. was established in October 1956, at the suggestion of Dr. Theodore von Kármán, as a joint project of the Governments of Belgium and the U.S.A. to provide intensive training in experimental aerodynamics, as well as in the broad field of fluid dynamics for engineers and scientists from N.A.T.O. countries.

The course of study is designed to give specialised training in the techniques and practices of a modern aerodynamics laboratory and lasts for 180 days. All lectures are offered in both French and English and about 75 per cent of the time is devoted to experimental work. Facilities include a 16 × 16 inch supersonic wind tunnel, one 3 meter diameter vertical tunnel for spinning tests, two closed return tunnels with a 3 meter (open throat) and 2 meter (closed throat) working section and one Eiffel type tunnel with a 2 meter (open throat) working section. Some hypersonic facilities are in the planning stage.

There is no tuition fee for the course and a limited number of scholarships is provided. Application forms and more detailed information may be obtained from Dr. R. P. Harrington, Technical Director, Training Center for Experimental Aerodynamics, 72 Chaussee de Waterloo, Rhode-Saint-Genese, Nr. Brussels, Belgium. Dr. Harrington was formerly Professor and Head of the Department of Aeronautical Engineering, Rensseler Polytechnic Institute, Troy, N.Y.

ACKNOWLEDGMENTS

An oil painting panel of a ballooning scene has been presented to the Society by Miss Jessie Barton of 40 Green Lane, S.E.20, who describes herself as elderly and "remembers it hanging on her grandmother's wall." Steps are being taken to have the panel cleaned and, if possible, identified. The Council wishes to thank Miss Barton most sincerely.

They also thank Mr. T. G. Edwards of 4 Mortimer Court, London, N.W.8, for the books he has presented.

NEWS OF MEMBERS

R. W. W. BUCKLEY, (*Associate Fellow*), formerly Superintendent of Electronic Laboratories of Canada Ltd. is now a Designer with the Boeing Aircraft Co., U.S.A.

D. J. COCKRELL (*Associate Fellow*), formerly Lecturer in Aeronautics, Hatfield Technical College, is now Senior Lecturer in Aeronautics, Loughborough College of Technology.

ROGER S. DICKSON (*Associate Fellow*), formerly with Lockheeds at Burbank is now Senior Design Engineer in Lockheeds Missiles System Division at Sunningdale, California.

G. P. DOLLIMORE (*Associate Fellow*), formerly of Hunting Percival Aircraft, Luton, is now a Research

Engineer in the recently formed Hunting Engineering Ltd., at Luton.

Wing Commander D. G. DUNPHY (*Associate Fellow*), formerly at H.Q. Flying Training Command, R.A.F., Berks., has recently assumed the appointment of Senior Technical Assistant to the Director of Military Aircraft Research and Development at M.O.S. H.Q.

P. G. FIELDING (*Associate Fellow*), is now with RESCO, Inc., a Research and Engineering Services Corporation at Sandy Springs, Georgia.

T. L. HALL (*Graduate*), formerly a Technical Assistant at Bristol Aircraft Ltd., is now a Technical Officer with Hunting Clan Air Transport Ltd., London Airport.

Wing Commander R. MILROY HAYES (*Associate*), is now on the Engineering Staff of the Nuclear Power Plant Company at Booth's Hall, Cheshire.

Group Captain A. A. F. HICKMAN (*Associate Fellow*), formerly Chief Aircraft Supplies Liaison Officer at the M.O.S. is now Senior Training Officer at R.A.F., St. Athan.

Squadron Leader P. T. V. JESSOP (*Associate Fellow*), is now with the Ministry of Supply in the Directorate of Guided Weapons (Trials).

Squadron Leader J. E. H. MARSHAL (*Associate*), has retired from the Royal Air Force and is now Chief Flying Instructor at the Iraqi Flying Club, Baghdad Airport.

A. MERTON (*Associate Fellow*), formerly with General Electric Co. Ltd., is now Chief Physicist, Nuclear Power Division, with Mitchell Engineering Ltd.

F. N. MONTAGUE (*Associate*), formerly of the Fairey Aviation Co. Ltd., is now employed by A. V. Roe and Co. Ltd. as Assistant Design Engineer at their Harrow Office.

C. NELSON (*Associate Fellow*), formerly Inspector of Armaments, M.O.S., is now Principal Inspector (GW)—Eng. I.

R. PARKER (*Associate Fellow*), has resigned his appointment as a Senior Scientific Officer at the National Gas Turbine Establishment, and has joined the Advanced Projects Design Section of Rolls-Royce Ltd., Derby.

A. G. PAYNE (*Associate Fellow*), formerly lecturer at Hatfield Technical College, has been appointed Principal, Government Technical Institute, British Guiana.

J. G. H. PEARCE (*Associate Fellow*), formerly of Sir W. G. Armstrong Whitworth Aircraft, Coventry, has now taken up an appointment as Organisation and Methods Controller with Rotol Ltd.

C. A. PENBERTHY (*Associate Fellow*), of Dowty Equipment Ltd., Arle Court, is now Commercial Manager at Dowty Hydraulic Units Ltd., Ashchurch.

P. PREECE (*Associate*), formerly with Malayan Airways in Singapore, is now Chief Inspector with Independent Air Travel Ltd., Bournemouth.

R. W. PRIZEMAN (*Associate Fellow*), formerly Chief Technician at Baynes Aircraft Interiors Ltd., has been awarded a King George VI Memorial Fellowship, to be taken at the Graduate School of Business Administration, University of California at Los Angeles.

W. A. E. PUNTIS (*Associate Fellow*), formerly with Skywork (Pvt.) Ltd., is now with The International Red Locust Control Service as Aircraft Engineer in charge of airspray engineering.

Squadron Leader J. N. QUICK (*Associate Fellow*) has been posted to No. 1 School of Technical Training, R.A.F. Halton, as Head of the Aerodynamics Section and Officer *i/c* Airframe Apprentices Science School. He will continue to act as technical adviser to the Shell Film Unit for the "High Speed Flight" series of films.

P. L. A. RAES (*Associate Fellow*), formerly Section Leader (G.W.) in the Engineering Development Laboratories, is now Test Superintendent (G.W.) with Bristol Aircraft Ltd., Birchgrove, Cardiff.

J. RAWCLIFFE (*Associate Fellow*) has obtained a temporary post with the Lockheed Aircraft Corporation, Georgia, as a Senior Design Engineer.

A. W. ROBSON (*Associate*), formerly an Instructional Engineer, is now a Technical Representative with de Havilland Aircraft Co. Ltd.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

William Adams
John Barton Armstrong (*from Graduate*)
Arthur Alan Arnold
Malcolm Keith Bowden (*from Graduate*)
Claude Walter Brenner (*from Graduate*)
John Bradley Chaplin (*from Graduate*)
Arthur Cecil Ronald Collins (*from Graduate*)
Qona Crawshaw (*from Associate*)
Graham Hopkin Davies (*from Graduate*)
James Robert Dixon (*from Graduate*)
Thomas Glenville Doe (*from Graduate*)
Peter George Edgington (*from Graduate*)
Kenneth Fearnside
Terence John Floyd (*from Graduate*)
John Gerald Franks
Norman Gardner
Julius Guest
James William Haggas (*from Associate*)
John Henry Heap
Hywel Raymond Hopkin
Alec Arthur Ince
P. Krishna Iyer (*from Associate*)
Thomas Benedict Jones
George Charles Brian Harvie Kenrick (*from Graduate*)
Albert William Kitchenside (*from Graduate*)
Kenneth John Lelliot (*from Graduate*)
Thomas Arthur Lennard
Haydn Sydney Liner (*from Graduate*)
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Raoul Gery Edward Mallin (*from Graduate*)
Robert Barry Matthews (*from Graduate*)
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Robert Vernon Moxey (*from Associate*)
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James Hay Stevens (*from Associate*)
Derwent Graeme Stewart
Darrol Stinton (*from Graduate*)
Gordon Stockdale
Thomas Hamilton Trimble (*from Companion*)
Eugene Emile Vielle (*from Associate*)
David Noel Vincent (*from Graduate*)
Eric John Warlow-Davies
Michael George Wilde (*from Graduate*)
Maurice O'Brien Wood Wolfe
Edward Stanley Frederick Wright (*from Associate*)

Associates

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Albon Beedle
Sydney John Blount
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Robert Henry Casbard
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Ian James Ford (*ex-Student*)
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John Alfred Radcliffe
Anthony William Russell
George Watson Smith
Robert Varley
Roger Robinson Warburton
Gerald Anthony Watson
Joseph James White
Robert Derek Wykes

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M. Ikramul Hassan

The Journal of the Royal Aeronautical Society
WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS
VOLUME 61 SEPTEMBER 1957 NUMBER 561

Some Thoughts on Aeronautical Research and Design

by

M. B. MORGAN, M.A. F.R.Ae.S.
(Deputy Director, Royal Aircraft Establishment)

1. Introductory

"To know, can only wonder breede,
And not to know, is wonders seede."

There is a peculiar magic in these lines of Sidney Godolphin, penned 300 years ago. I can think of no better introduction to a paper on aeronautical research and design.

Flying is rather a remarkable business, about which we are inclined to get a little blasé nowadays. Few things can tax the engineers' skill more than the design of a modern high performance aeroplane. In its way it represents supremacy in engineering achievement. Let us not take all this too much for granted; and let us remember those gifted designers—no longer with us—who laid the foundations of the art. Among these, the name of Roy Chadwick stands high.

As a representative of one of our research Establishments, I deeply appreciate being asked to give this Second Memorial Lecture in honour of Roy Chadwick. There is no need for me to write a eulogy of the man and his work—this has already been done so admirably by Rogerson in the First Memorial Lecture. I myself have the happiest recollections of contacts with Chadwick and his design team, particularly in those exciting years when the first big multi-engined monoplanes were emerging from the drawing board and being made to work in flight. He had a great singleness of purpose; he knew what he wanted and how to get it; he knew when and how to accept or reject advice; he was a master of compromise; he was above all a lover of aeroplanes and all that went with them. We miss him very much.

My intention is to outline a few of the directions in which research might take design in the next decade or so, touching on some of the problems which will face us all on the way; to sketch some of the more modern tools of the aeronautical research trade; and to conclude with a few thoughts on the way in which research and design teams go about their affairs. My thanks are due to my colleagues at the Royal Aircraft Establishment who have helped me to assemble the material; I am also grateful to the Ministry of Supply for authority to give this lecture.

*The Second Chadwick Memorial Lecture; given to the Manchester Branch of the Society on 13th May 1957.

PART I—THE WAY AHEAD

1. The Expanding Picture

Aeronautics is concerned with the transport of useful load—be it passengers, troops, goods, guns or warheads—by means other than sitting it on the sea or trundling it over the land. All aeronautical projects without exception have certain common elements—be they for transporting strawberries from the South of France to London or sending a bomb half-way round the world. The carrier itself; means for keeping the useful load in good condition throughout its journey; and apparatus for navigating the carrier so that it gets its load to the right place at the right time. Economically, all these component parts of a project have had to make reasonable sense as a "system" ever since the start of aviation. Before the 1939-45 War, it was easier technically to separate out individual elements. Since the war, particularly with the advent of pilotless carriers, the technical fusing together of the various parts of a "system" has become more obviously a necessity.

In the past few decades or so, the whole field of aeronautics has expanded with great vigour in meeting or anticipating civil and military needs. Some things have fallen by the wayside—the free balloon, the airship and, to some extent, the flying boat. But new forms of propulsion have already given us the means of carrying large loads over long distances at speeds not far below the speed of sound—the large subsonic jet transports and bombers are with us. The helicopter has emerged as a practicable flying machine. Manned flight at transonic and supersonic speeds is an everyday occurrence. Pilotless techniques, combined with ramjet and rocket-propelled vehicles, have opened up new military possibilities—from the short range highly manoeuvrable anti-aircraft guided weapon to the long range ballistic missile which spends most of its journey outside the atmosphere. The small unmanned satellite is almost in being, while the possibilities of space travel are being debated seriously by reputable scientists and engineers. Atomic propulsion may well bring quite new approaches to flight both inside and outside the atmosphere, and quite new methods of generating thrust and lift when flying at extreme speeds and heights may appear.

Quite apart from this catalogue of new regimes of endeavour, there will remain an immense amount of work to be done—both by research establishments and designers—in improving the safety and efficiency of aeronautical systems within existing speed and height brackets. The end has not yet been seen of the struggle to keep approach and landing speeds down without ruining economy; the use of the engines to give lift and control as well as thrust—as in the jet flap or vertical take-off aircraft—is in its infancy. Considerable advances have been made in devising methods of getting high performance aircraft safely to earth in all weather conditions, but a great deal more research lies ahead. I doubt if we have heard the end of the laminar flow controversies.

The point to be made from the picture I have tried to sketch is that aeronauts should not be short of things to do. As in the past, some of the lines of research and development pursued by Industry and the Establishments will lead to products which, although useful for a time, will be superseded as were the balloons. These will be more than compensated by the avenues which get more and more attractive as knowledge grows.

In the end, whether a particular line of work flourishes or dies depends on the cold economics of its value to the community—be it measured in monetary or military terms. In this context, the broad aeronautical scene is so vigorous and has so much to offer that I can visualise few fields of scientific and engineering activity with a more stimulating future.

In a general lecture it is obviously impossible to pick out more than a few items for discussion. I would like to dwell a little on some performance aspects of supersonic aircraft with air-breathing engines, and to follow up with a few remarks about rockets.

2. The Air-Swallowing Supersonic Aircraft Designed for Range

If we consider the problems of economical flight over medium to long range (1,000 miles and over) it is fairly well established that at subsonic speeds it pays to design jet transports to cruise as fast as they can without running up the compressibility drag rise. This means that, apart from the sheer convenience of speed, in terms of hard economics a Mach number on the cruise of, say, 0·8, is cheaper than a Mach number of 0·5.

The longer the range, the more attractive does speed become from the passengers' viewpoint. Now that information is building up rapidly on the propulsion, aerodynamic, and structural aspects of supersonic flight, it is interesting to speculate on the design problems associated with longish range supersonic aircraft, over the Mach number region of, say, 1·0 to 5·0.

(*i*) *Propulsion*

Starting with propulsion, a dominant parameter is intake efficiency. The sort of values which might be attained by pretty advanced design are illustrated in Fig. 1; at the higher Mach number increasing cleverness will be needed to reach the curve given, and it is possible that in the neighbourhood of a Mach number of 5·0 aerodynamicists will abandon the unequal struggle and turn to rockets.

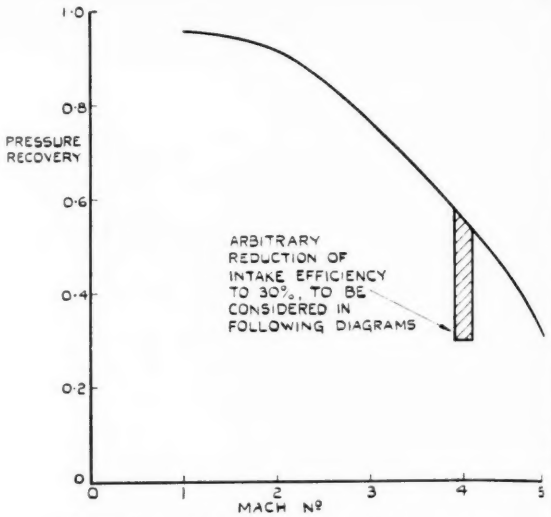


FIGURE 1. Intake efficiency against Mach number.

Behind the intake, one can put a turbo-jet engine, a ram-jet or a turbo-rocket. A rough criterion of merit of the intake/engine combination is Mach number/specific fuel consumption, since this appears in the range equation. It is plotted in Fig. 2(*a*)—the actual numbers are purely illustrative, but suffice to indicate that—while the turbo-jet is a useful power unit up to Mach numbers of 2½ to 3, thereafter it takes second place to the ram-jet. Use of the ram-jet will, of course, bring in its train the introduction of subsidiary booster units to accelerate the aeroplane up to a sufficient speed for ram-jet thrust to better aircraft drag.

(*ii*) *Lift/Drag*

Turning now to lift/drag ratio when cruising—the other factor of paramount importance in getting range—the sort of values which might be achievable with practicable aircraft are indicated in Fig. 2(*b*). Again the numerical values are merely illustrative, but we must expect a trend of the sort shown. As the speed increases, L/D will fall rapidly from its subsonic value, and will subsequently tail off more gradually at the higher Mach numbers.

Many factors come into this: optimum aspect ratio decreases as Mach number increases—arising from mixed structural and aerodynamic considerations. At lowish supersonic speeds there are possibilities of keeping wing wave drag small—the area rule or "shock cancellation" story—but this gets more difficult as speed increases. Once Mach numbers of about 2·0 are exceeded the drag coefficient at zero lift tends to fall away, whereas drag due to lift rises and results in a continuous deterioration of L/D. Paradoxically, we are on surer ground in estimating L/D at the higher Mach numbers, when fully supersonic flow patterns are established, than in the lower supersonic speed region where—with sweep—we may have large areas of quasi subsonic flow.

(iii) Generalised Performance Trends

Supersonic aeroplanes will have long and slender fuselages, very thin wings whose aspect ratio and plan form are tailored to the Mach number, and will be stabilised directionally with a fin at the rear; longitudinal stability may be achieved by tailplanes, foreplanes, or by choice of plan form and c.g. position with no tail at all. Below Mach numbers of 2·0 they may be built of light alloy. Above a Mach number of 2·0 a structural material such as steel, with superior high temperature characteristics to light alloy, will be needed from kinetic heating considerations.

Taking the curves already given for engine characteristics and L/D, and assuming a figure of (empty weight)/(all-up weight) of 40 per cent, Fig. 3 illustrates the likely trend of percentage payload with design Mach number for two stage lengths—3,200 nautical miles and 1,600 nautical miles. To illustrate how sensitive such aircraft are to changes in L/D or intake efficiency, the effects of dropping L/D to 6, or of only achieving an intake efficiency of 30 per cent at $M=4{\cdot}0$ are brought out in Fig. 4. The longer range machines can be seen to be desperately touchy to such changes.

Percentage payload falls off as speed rises, but a more cheerful impression can be gained by plotting speed × percentage payload, a quantity which to some extent is a measure of the economics of the operation. This is done in Fig. 5, and it will be observed that on this basis the shorter range machine gives encouraging values up to quite high Mach numbers. Too much should not be read into these figures; speed × percentage payload is only a crude criterion of economy, since it ignores the rise in fuel costs with high utilisation; while the assumed 40 per cent for empty weight/all-up weight is undoubtedly optimistic, particularly for the short range machines. But the broad lessons from studies of this sort are clear.

(*i*) The longer the range, or the higher the air speed, the greater is the effect on operating economics of given percentage improvements in lift/drag, specific fuel consumption or basic aircraft weight.

(*ii*) Economic flight at high supersonic speeds will only be achieved by extreme and simultaneous efforts on the part of the engine people to improve specific fuel consumption; by the aerodynamicists to bring up L/D; and by the structures teams to reduce percentage structure weight.

(*iii*) Given such efforts, an aircraft with a stage length of about 1,600 nautical miles at speeds of about $M=2{\cdot}0$ seems not unreasonable.

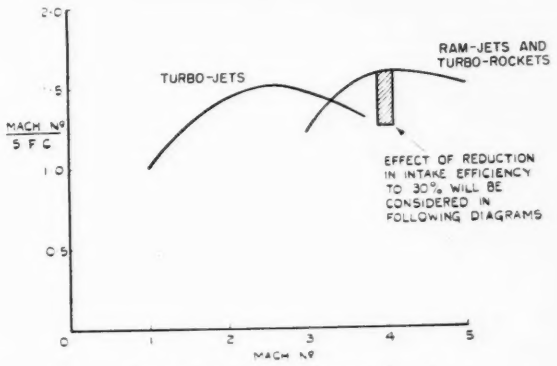


FIGURE 2(*a*). Engine figures of merit.

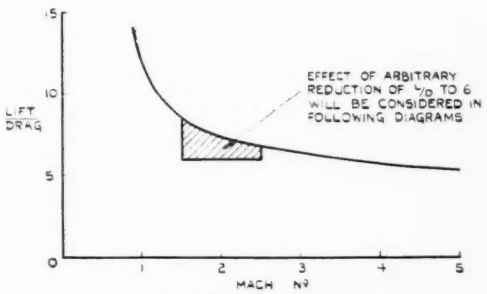


FIGURE 2(*b*). Lift/drag.

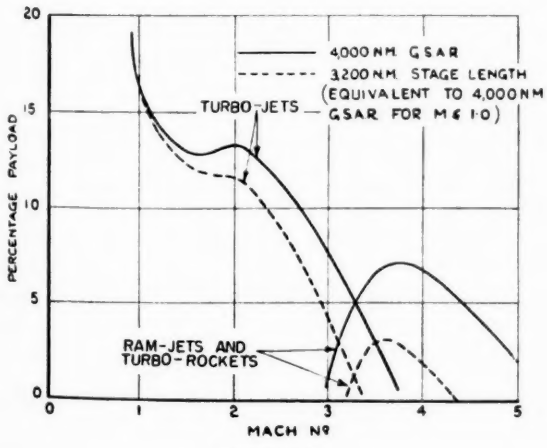


FIGURE 3(*a*).

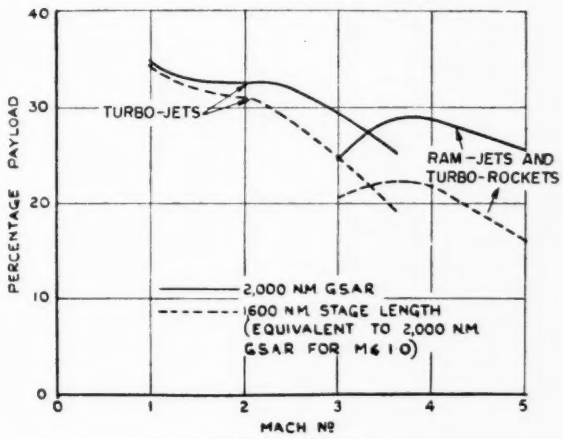


FIGURE 3(*b*).

Load-carrying capacity of supersonic aircraft. (Weight less fuel and payload=40% of A.U.W. for all aircraft.)

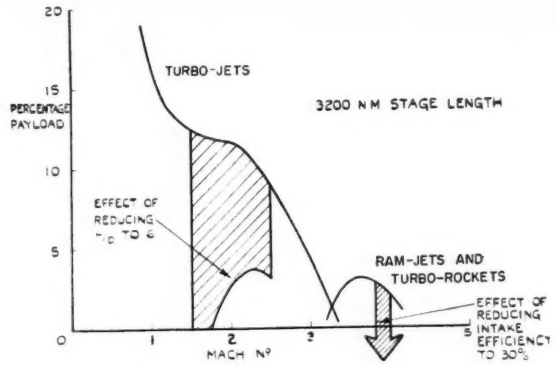


FIGURE 4(*a*).

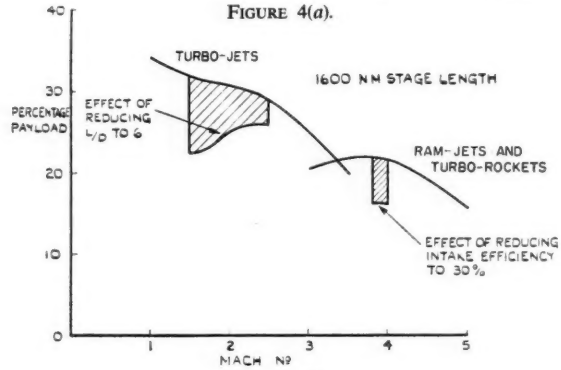


FIGURE 4(*b*).

FIGURE 4 (*a* and *b*). Percentage payload-design sensitivity.

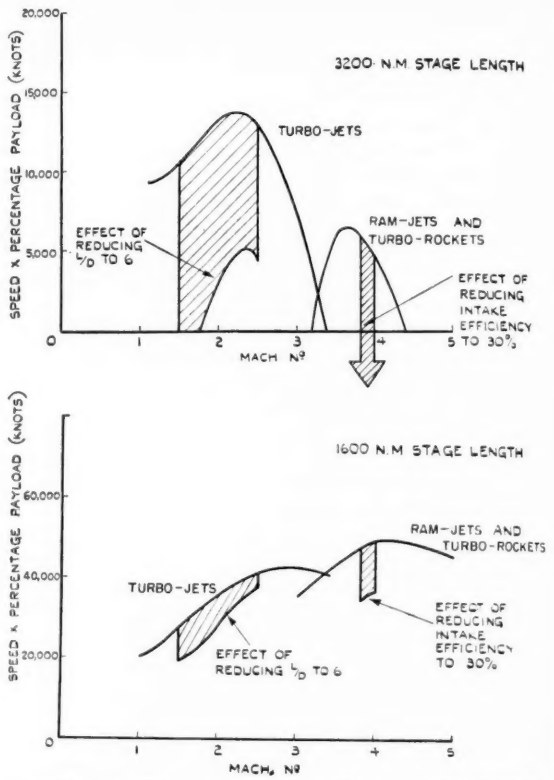

3200 N.M STAGE LENGTH
SPEED × PERCENTAGE PAYLOAD (KNOTS)
TURBO-JETS
EFFECT OF REDUCING L/D TO 6
RAM-JETS AND TURBO-ROCKETS
EFFECT OF REDUCING INTAKE EFFICIENCY 5 TO 30%
MACH Nº
1600 N.M STAGE LENGTH
TURBO-JETS
EFFECT OF REDUCING L/D TO 6
RAM-JETS AND TURBO-ROCKETS
EFFECT OF REDUCING INTAKE EFFICIENCY TO 30%
MACH Nº

FIGURE 5. Speed × percentage payload—design sensitivity.

Greater ranges at these high speeds are farther off for passenger aircraft which pay their way.

(*iv*) *Wing loading*

The possible trend of wing loading with Mach number is illustrated in Fig. 6. The take-off distances of the turbo-jet machines should not be unreasonable, but much research will be needed to get acceptable landing performance since, although some relief is afforded by the large percentage fuel weight which disappears for the landing, this is offset by the very poor $C_{L\max}$ of low aspect ratio thin wings; every effort will have to be made to improve this by such devices as flaps and drooped leading edges, possibly combined with blowing. Ultimately, certain of the supersonic configurations may lend themselves to vertical take-off and landing by use of lifting engines.

(*v*) *Stability and Control*

Supersonic flight with economy involves cruising at great heights. At a given indicated air speed, increase of height automatically increases the magnitude of the inertia forces during manoeuvres and oscillations, as compared with the aerodynamic forces. Illustrative examples of the trends with speed and height of longitudinal period and damping are given in Fig. 7. While the problems of providing the pilot with adequately powerful control moments and adequate static stability seem tractable up to quite high Mach numbers, artificial stability devices to improve damping coefficients may prove essential. Static directional stability may become an awkward problem at Mach numbers exceeding 2·0, and artificial stability may again be needed here to keep fin size within bounds.

(*vi*) *Other Points*

Supersonic flight will involve hosts of problems which cannot be dealt with here—high temperature materials not only for the main structure but also for such items as transparencies; thermal insulation and refrigeration of certain parts to keep the crew, passengers and equipment in proper shape; navigational methods; and so on. The noise difficulty should be mentioned. By suitable flight programming the sonic bang problem can possibly be kept within bounds; but airport noise—particularly during take-off and climb away—may prove a real hurdle which, for civil aircraft operating near densely populated areas, will demand quite special attention from the engine designers.

3. Rocket-Propelled Long Range Aircraft

If air-swallowing engines become more difficult beyond $M=5{\cdot}0$, it is tempting to consider whether manned devices can be evolved to carry speed still farther. Rocket propulsion is the obvious way of going about it.

Four points of difference between the air-breathing engine and the rocket are, very broadly:—

(*i*) Rocket performance is pretty well independent of speed.

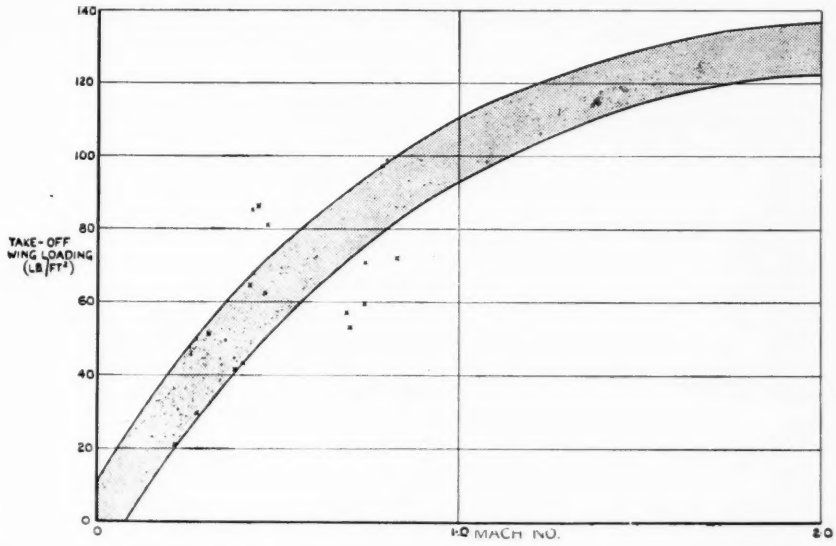


FIGURE 6. The trend of wing loading with Mach number.

(*ii*) Rocket performance is nearly independent of altitude.

(*iii*) Motor weight per unit thrust is very low.

(*iv*) Fuel consumption is very high.

(*i*) and (*ii*) give us an extra degree of freedom in the choice of flight path—we need not settle for constant speed cruise. (*iii*) means that rapid acceleration can be provided at little cost in weight. (*iv*) suggests that burning time should be short.

It can readily be shown that to achieve range, the best procedure is a short period of acceleration to as high a speed as possible, followed by a much longer period of gliding at maximum L/D. The great benefit of going as fast as possible stems from glide range being proportional to the square of the maximum speed if glide deceleration is constant—as it should be if L/D does not vary.

A maximum speed of 10,000 ft./sec. (Mach number about 10) would give a glide range of about 1,250 nautical miles at a L/D of 5·0, with a further 100 miles thrown in during acceleration. The height at the start of glide would be 120,000 ft., dropping to about 50,000 ft. at a Mach number of 2·0 towards the end. Small auxiliary engines would be needed for the final landing.

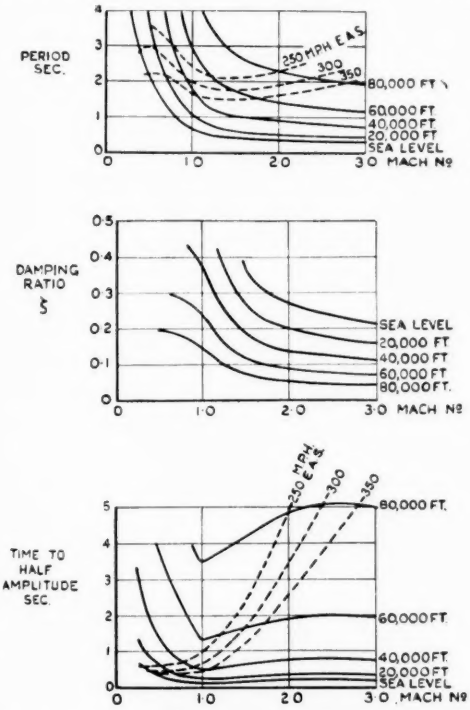


FIGURE 7. Damping and period of longitudinal short period oscillation-variation with speed and height.

This is an intriguing possibility, but more detailed calculations suggest that as a passenger carrier it would present rather devastating problems. A very large boosting device would be needed to get the aeroplane up into thin air and partially up to speed, the aeroplane subsequently separating from the boost. If the boost were expendable, the economics of the operation would not be attractive. The aeroplane itself would have to achieve a very low structure weight in the face of severe kinetic heating.

While we can safely place this theme more distant in time than the air-swallowing supersonic aircraft, the story is quite different in relation to short endurance piloted research aircraft. A rocket-propelled experimental machine may well prove to be an essential and practicable step for exploring flight behaviour with high kinetic heating rates at extreme speeds.

PART II—TOOLS OF THE TRADE

1. General

Before the 1939-45 War the research tools needed by the aeronautical scientist were beginning to increase rapidly in cost and size. I remember those of us brought up on small wooden atmospheric wind tunnels feeling that we were entering a strange new world when the "high speed tunnel"—the first big pressurised tunnel for high subsonic work at Farnborough—came into being. During the past 20 years, the growth of large scale research apparatus has been impressive. It has been made inevitable because the tasks foreseen—the development of larger and much faster aircraft, the exploitation of new forms of propulsion such as the

ram-jet and the rocket, the fostering of guided missile design—could not be tackled without sweeping changes in our experimental methods.

I intend to touch on a few of the more massive and costly technique themes in which we at the Royal Aircraft Establishment have considerable interest:—

(*i*) The transonic tunnel.
(*ii*) The large supersonic tunnel with flexible walls.
(*iii*) Free flight model techniques.
(*iv*) Structural testing with simulated kinetic heating.
(*v*) The research aircraft.

This list is of course by no means inclusive—large scale capital facilties are involved in guided weapon ranges, airfields with large runways, naval carrier equipment test sites, structural, static and repeated load test apparatus, and so on.

While the string and sealing wax approach no longer suffices in aeronautical research, its days are by no means numbered. A vast amount of extremely valuable original work can still be done with quite small scale gear and with computational apparatus no more complex than a slide rule. All structures specialists do not spend their time in vast test frames; quite small specimen tests are vital. The big wind tunnels must be supported by hosts of small tunnels. There is indeed a danger—felt particularly by people of my generation—that the younger aerodynamic workers can become too divorced from the air and from the models, which are shut away in inaccessible containers and viewed second hand by television; while the steel models themselves are costly, take a long time to make, and cannot be altered quickly. In order to get a "feel" for the problems of air flow there is a lot to be said for the old atmospheric low speed tunnels in which the models were wood, could be made quickly and could be altered in minutes with the aid of masses of plasticine; and in which, with the aid of easily lashed up probe and wool tuft arrangements, you could readily see what the air was doing. There is much to be gained by giving the staff using large supersonic tunnels the opportunity from time to time of working with much smaller tunnels, in which new ideas can be followed up much more quickly and modifications to models and apparatus made more easily.

Having said all this, the hard fact remains that the designers cannot be given what they want without obtaining detailed results from the big facilities. They are an inescapable part of the modern scene, and add considerably to the responsibilities of a modern aeronautical research institution whose staff must not only sense the need for new apparatus, but must also face the often novel problems of getting such apparatus designed and built.

2. The Transonic Tunnel

For some years models could be tested in wind tunnels at low speeds and at fully supersonic speeds, but tests at or near the speed of sound—the so-called transonic region—were impossible because of the difficulties in setting up steady flow conditions in a wind tunnel near sonic speed. This gap in our armoury has been filled by the evolution of "slotted wall" techniques, whereby the working section is ventilated and an acceptable flow pattern obtained; transonic tunnels are now operating in most countries seriously engaged in aerodynamic work.

Slotted wall techniques were explored at Farnborough and Bedford on a smallish scale, and it was finally decided to convert the old "high speed tunnel" at Farnborough to transonic working by greatly increasing the horsepower in conjunction with a completely redesigned working section.

The original "high speed" tunnel is of considerable sentimental interest to us at Farnborough, owing to the yeoman service it gave during the War years and afterwards. Construction began in 1939, and it was completed in 1942. As originally conceived it was a variable density tunnel (Fig. 8) in which tests could be done at Mach numbers up to 0·8, at Reynolds numbers

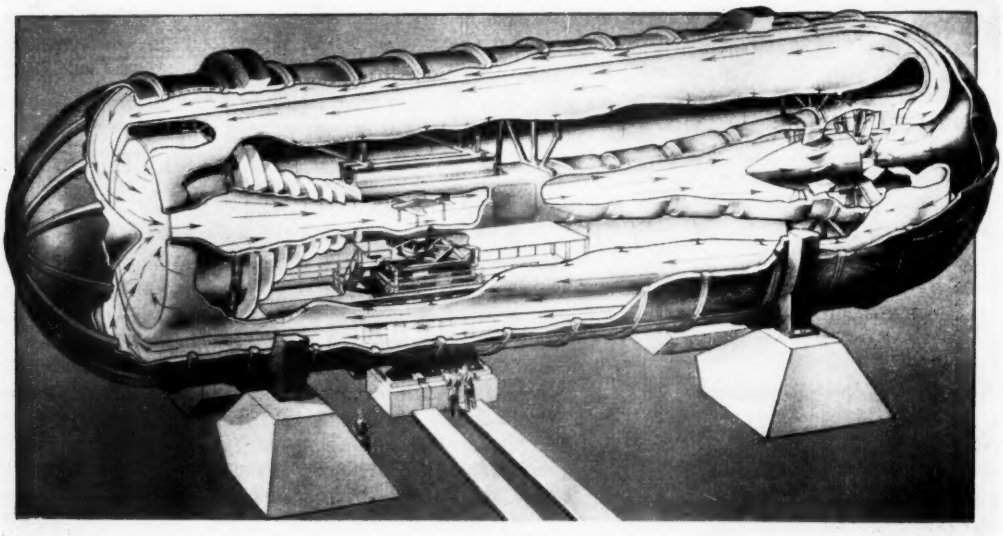


FIGURE 8.
Original R.A.E. "high speed wind tunnel."

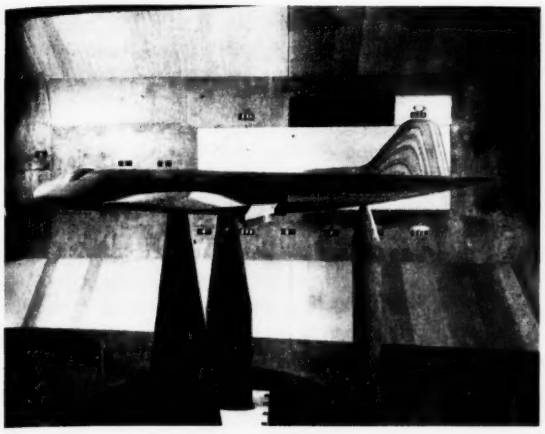


FIGURE 9. Canberra in high speed wind tunnel.

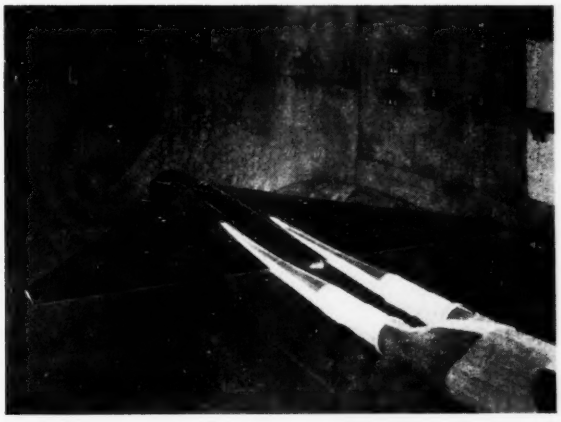


FIGURE 10. Vulcan in high speed wind tunnel.

of about $1{\cdot}4 \times 10^6$ per ft.; at lower speeds, Reynolds numbers of as much as 5×10^6 per ft. could be obtained. The working section was 10 ft. × 7 ft. During the life of the tunnel speeds were increased by sundry internal modifications, by modifying the model support from struts to sting, and by reducing model size. Mach numbers exceeding 0·9 were thereby achieved, and nearly all our best known British designs went through this tunnel. Fig. 9 shows the Canberra sitting on the old strut supports, while Fig. 10 illustrates the Vulcan on its sting. While inevitably carrying a large load of "*ad-hoc*" work, a great deal of more general research was undertaken after the war—particularly on the three-dimensional flow at high subsonic speeds past wing body combinations.

The tunnel has now been given a new lease of life by its conversion to transonic working, which has involved a considerable increase in horsepower (while

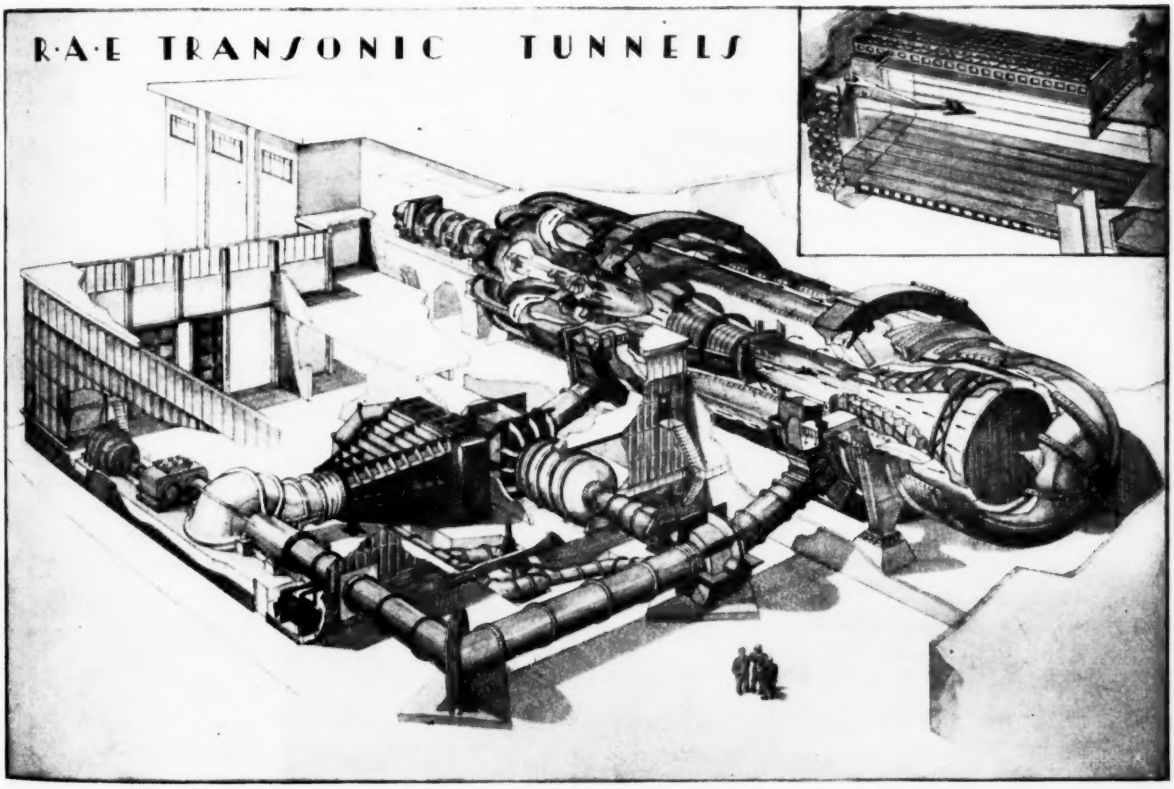


FIGURE 11.

retaining, surprisingly enough, the original fan). Fig. 11 illustrates the tunnel in its new form. The working section is 8 ft. × 6 ft., and tests can be done up to a Mach number of 1·25, where a Reynolds number of $3\frac{1}{2} \times 10^6$ per ft. is available; at lower speeds Reynolds number can be increased to 9×10^6 per ft. By any standards this is a pretty useful piece of apparatus, and —taken in conjunction with the new A.R.A. transonic tunnel near Bedford—it should serve research and design in this country well for many years to come.

Satisfactory transonic experimental methods are essential, not only for transonic but for supersonic designs, since the thrust/drag balance and the handling characteristics of supersonic machines must be acceptable in the transonic region, even though the aircraft only spends a short time of each flight at such speeds. The free flight rocket model technique, which will be described later, is no substitute for systematic wind tunnel work at these awkward speeds where mixed flows are present; it is merely a useful adjunct.

3. The 8 ft. Supersonic Tunnel

This tunnel, now in being at R.A.E. Bedford, is possibly the most formidable aerodynamic research tool which we have at our disposal, and great things are hoped for it.

Figure 12 illustrates the tunnel, while the layout is given in Fig. 13. The tunnel working section is 8 ft. × 8 ft., and a Mach number of 2·8 is attainable. The main drive absorbs 80,000 h.p., and the auxiliaries 8,000 h.p., while working pressure ranges from 0·1 to 4 atmospheres.

At the higher Mach numbers a Reynolds number of $2{\cdot}5 \times 10^6$ per ft. is available, rising to 7×10^6 per ft., at subsonic speeds. Flexible walls form the supersonic nozzle upstream of the working section; both Reynolds number and Mach number are continuously variable. The tunnel is therefore particularly versatile.

The whole idea of the tunnel is to accommodate models large enough for reasonable detail to be represented at fairly high Reynolds and Mach numbers. The complete models will be about 6 ft. long, and with this scale it is possible to represent details such as dive brakes; to provide internal ducts to obtain correct flow at engine intakes; and to instal strain gauges members to measure hinge moments on control surfaces. The models are mounted on a sting fitted with a six component balance, and extensive pressure plotting facilities have been planned. Much thought has been given to flow visualisation techniques, while the model itself is under continuous observation by means of a closed circuit television gear.

With such a valuable piece of equipment it is important that the raw data emerging from the measuring elements should be analysed and processed with the utmost speed. Elaborate machinery has been installed whereby the data are automatically analysed and recorded. The stressing and design of the steel models is an intricate business almost comparable to the design of a small aeroplane, while the final manufacture of the models to extremely fine tolerances—particularly on surface waviness—has demanded new machine tool techniques. Speed of model manufacture is essential if full use is to be made of such a tunnel in advancing aerodynamic design, and considerable thought has been given to methods of cutting down model design and manufacturing periods to an acceptably low figure.

FIGURE 13 (*above*). R.A.E. Bedford — layout of 8 ft. supersonic wind tunnel.

FIGURE 12 (*left*). R.A.E. Bedford — 8 ft. supersonic wind tunnel.

4. Free Flight Rocket Model Techniques

Possibly because of their familiarity with rockets, the guided weapon people pioneered the serious use in this country of smallish rocket-propelled models to explore in free flight aerodynamic behaviour at high Mach numbers. The aeroplane workers quickly followed suit and extensive firings are now done regularly at Larkhill and Aberporth, both of aircraft and guided missile shapes.

Solid fuel rockets are used, and they may either be integral with the model or may separate at all-burnt, leaving the model coasting on during the measurement phase. Velocities are obtained from the usual Doppler technique or from kiné theodolites, while physical quantities such as pressures, temperatures, forces, moments, accelerations and angles are measured internally and transferred to the ground by telemetry.

Figure 14 shows a model by itself, while Fig 15 indicates the model mounted pick-a-back on its boost. A typical firing is illustrated in Fig. 16.

The technique lends itself well to a study of overall stability and control, by exciting and studying the short period oscillation—longitudinal or directional—induced by movement of a control surface or by small "bonker" rockets. Drag at zero lift is also readily studied. Measurement of drag at high lift is more difficult, making much larger demands on accelerometer technique. Pressure measurements are regularly taken, during base-drag and intake work. Valuable information on heat transfer can be obtained from thermocouples spot welded to the inside of a thin walled outer shell. The technique regularly covers Mach numbers of from 0·8 to 5·0 and above, an increase in Mach number being quite readily attained.

Herein lies the main beauty of this free flight technique—it is relatively *flexible*. If a new Mach number region needs exploring, you can get into it far more quickly with a free flight model than by waiting for a massive piece of laboratory equipment to be designed and built. The models themselves are also usually easier to construct than large wind tunnel models. A wind tunnel, however, scores handsomely both in the accuracy achievable and in the comprehensiveness of the data which can be obtained. There is no conflict between the techniques, which are complementary. The free-flight model is particularly useful in:—

(*i*) obtaining quick advance information on urgent design problems.

FIGURE 15 (*right*). Free flight model on boost.

FIGURE 14 (*below*). Typical free flight model.

(*ii*) giving a broad check on detailed stability and control tunnel measurements.

(*iii*) giving early information on behaviour at extreme Mach numbers.

Apart from purely aerodynamic work, free-flight models are also extensively used for flutter and aeroelastic investigations. To both the aerodynamic and structures teams a free-flight firing range is therefore nowadays an essential research adjunct.

5. Structural Testing with Simulated Kinetic Heating

The "heat barrier" has been discussed so thoroughly of late that there is no need to dilate on the

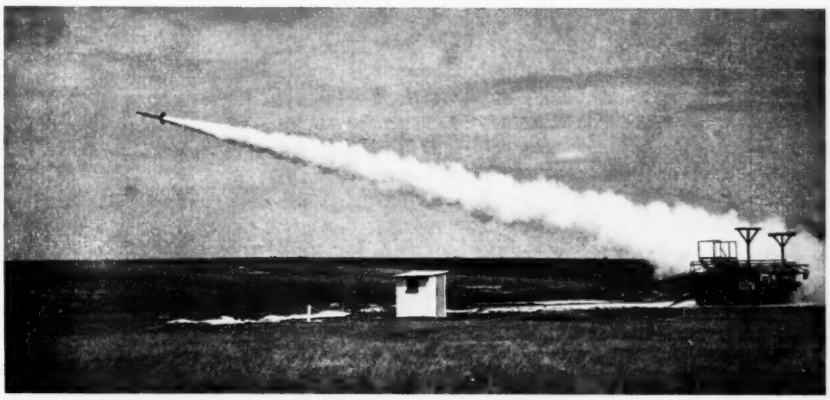


FIGURE 16. Free flight model—view during firing.

fact that when air is slowed down, relative to the aeroplane, it gets hot. Before the 1939-45 War this effect was of little consequence to aircraft designers; those concerned with aircraft performance testing met it in a mild way in connection with the correction to be applied to the old strut thermometer for "adiabatic rise" when measuring air temperature. The correction was conveniently $(V/100)^2$°C, where V is the speed in m.p.h. At 100 m.p.h. we only had 1°C to worry about. Once we start thinking of speeds of 1,000 m.p.h. and above, the effect becomes formidable, as illustrated in Fig. 17.

The mechanism whereby the surface of a fast flying machine heats up at high speeds is complex, although nowadays increasingly well understood. The temperature which the air would like the outer skin to attain depends on speed, height, and boundary layer condition; while radiation from the surface can have a powerful ameliorating influence, as illustrated by the lower curves of Fig. 17—particularly at very great heights and high Mach numbers. The significance of Fig. 17 from the structural angle can be appreciated if it is recalled that aluminium alloys begin to be suspect above about 150°C; that titanium alloys show unacceptable creep characteristics above 350°C; while steels should take us to 600°C, above which nickel based alloys may come in.

The structural problem would be much more straightforward if all we had to deal with were elevated temperatures that were steady. Obviously, however, before steady conditions can be reached during, say, a relatively lengthy cruise at supersonic speeds, the whole heating situation is extremely unsteady—the aeroplane is suddenly heated severely externally and complex heat flows take place inwards; the situation is reversed when the aeroplane—having spent some time at high speeds—suddenly slows down. While calculation and small scale specimen tests can take us some way in understanding the influence of such dynamic effects on strength and stiffness, to get to grips with a large and complex structure the full scale specimen must be tested under thermal conditions approximating

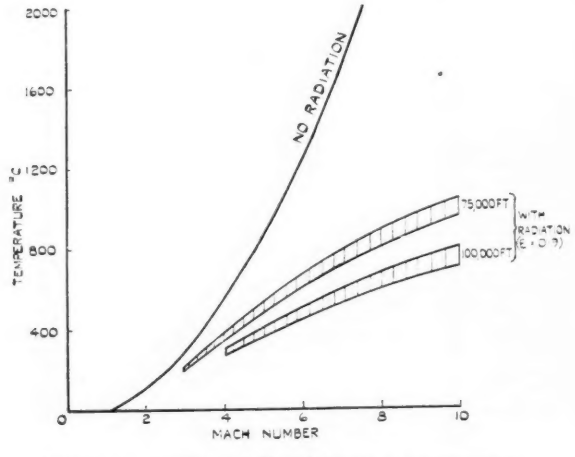


FIGURE 17. Illustrative "Kinetic heating" temperatures.

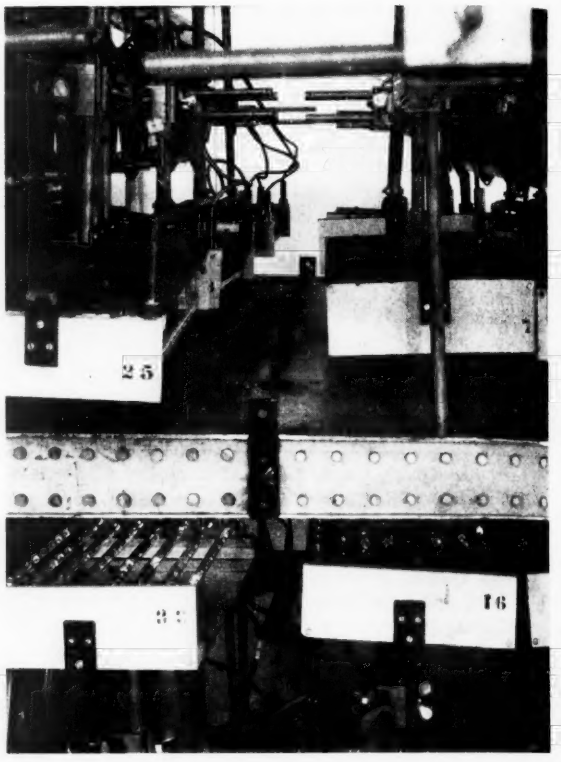


FIGURE 18. Structural tests with simulated kinetic heating.

to those expected in flight. This means that intense sources of heat must be applied locally outside the structure; and that very quick response sources must be developed to simulate the rapid changes in heat flux which occur when the aeroplane accelerates or decelerates.

Such apparatus has been developed successfully at Farnborough, in the form of infra red ovens using Phillips lamps—each oven capable of housing up to 24 lamps in front of a polished reflector. The unit is 14 in. long by 8 in. wide, and can generate about 130 kW./sq. ft.; with the unit 3 in. from the surface of the structure, and the surface itself well blacked, it is possible to get 60 kW./sq. ft. into the structure. Fig. 18 illustrates such ovens in place adjacent to a specimen; by leaving gaps between the ovens of about 2 in. there is room for individual loading links of a standard multi-lever loading system to be brought down to the specimen through the oven assembly. The individual ovens are arranged to be held at a fixed distance from the surface, moving with the structure as it deflects.

During transient heating tests the ovens must be controlled individually, or in small groups, to simulate correctly the changing heat inputs over the surface of the aeroplane. From the assumed flight pattern, aerodynamic heating functions are calculated before the test starts and stored; as the test proceeds, surface temperature is measured under each oven and is fed back into a computer which—from a knowledge of the

flight programme and the aerodynamic functions—continuously adjusts the voltage on the oven to give the requisite heat flow. Since very large numbers of ovens must be controlled individually when dealing with a big structure, a formidable mass of computers and controllers is involved, and there is scope for much ingenuity in cutting down the cost and size of the whole scheme by time sharing devices, whereby one computer deals in rapid succession with a number of heat controllers. Testing larger specimens is, however, bound to involve apparatus much more complex than we have been used to in the past. This is the price we must pay for flight at high supersonic speeds—without such structural test facilities the development of high speed aircraft which keep us in the van of progress will not be practicable; the kinetic heating structural test frame is an essential complement to the large supersonic wind tunnel.

6. The Research Aircraft

Of all the aeronautical research tools we know, this is possibly the most powerful. Two examples of such aircraft, both built under the aegis of the Ministry of Supply and now in the middle of flight programmes at the Royal Aircraft Establishment, are the Rolls-Royce Flying Bedstead (Fig. 19) and the Fairey F.D.2 (Fig. 20). These are at opposite extremes of the vastly extended speed range now of interest to us—the one designed for exploration of the problems of vertical take-off and landing, the other already the holder of the World Speed Record.

Nothing gives more "bite" to a research programme than having an experimental machine at the end of it to check in flight the results of theoretical and experimental work in the laboratories on the ground.

Economically it is not feasible to build facilities large and complex enough to simulate with confidence final behaviour in flight; we go as far as we dare, certainly far enough to enable design to proceed with reasonable

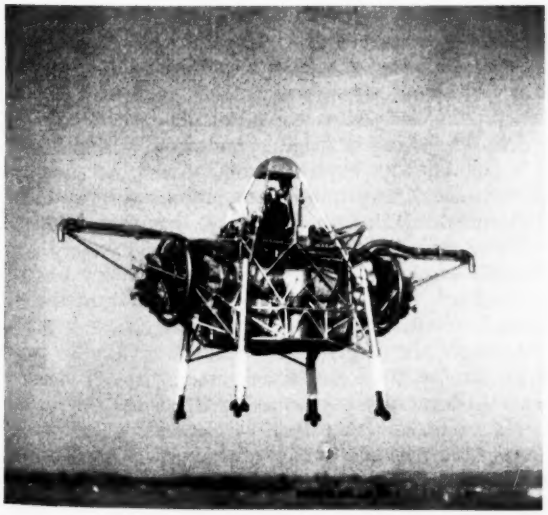


FIGURE 19. Rolls Royce Flying Bedstead.

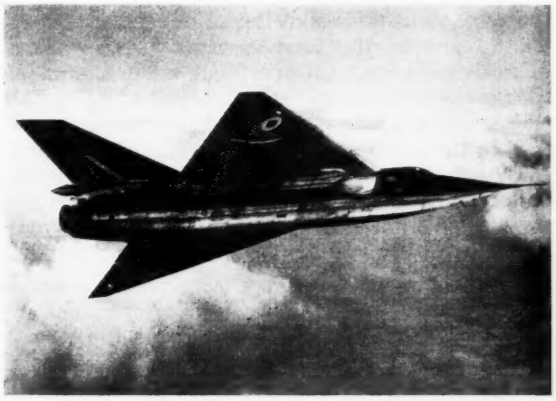


FIGURE 20. Fairey F.D.2 research aircraft.

confidence; but finally—even for the more obvious and measurable parameters—full scale measurements are the test. Often as a result of, say flight/wind tunnel comparisons, the utility of the wind tunnels for predicting the behaviour of still newer types of aircraft as yet unflown is enormously increased. Quite apart from the more straightforward parameters which can be isolated and measured to give the essential flight/tunnel checks, there are many aerodynamic and structural effects—particularly in unsteady motion—which can only really be studied conclusively in flight; only after the flight observations can detailed mathematical and experimental work be initiated in order to explain the observed behaviour. A surprisingly large proportion of an aeronautical research programme derives from observations made originally in flight—either on research aircraft or during development tests of operational aircraft. The general pattern of research on the ground is, first, looking ahead to get a reasonably successful machine; then, when the machine is flying, looking back and doing a lot more work to understand more fully flight behaviour. From the viewpoint of the designer, research inspired in this latter way is often particularly valuable for the next generation of aircraft.

While much useful research can be done in flight on standard aircraft modified slightly to suit the programme—a typical example is the exploration of laminar flow by the addition of suitable "gloves" to the wings of an existing aircraft—special aircraft must frequently be built specifically for the job. As we extend the speed and altitude range of manned aircraft, specially built research machines must play an ever-important role. Flight research is expensive, since, to guard against lengthy unserviceability or loss, at least two of a type must be ordered and, preferably, three. An interesting variant of the special research machine is the flying piloted model of a new operational type, built ahead of the full-scale prototype to get advance information. A policy of flying models was adopted by Avros during the Vulcan development, with conspicuous success.

One cannot leave the subject of research aircraft without a tribute to the men who fly them. I have been

privileged to know many of our test pilots, both in Industry and at the Establishments. Their general calibre is quite extraordinarily high, both in terms of flying skill and of technical understanding. The difficulties of the job have increased year by year, but—aided by the activities of the Empire Test Pilots' School—the pilots have more than adequately met the challenge.

7. Computers

Many other of the newer aeronautical research facilities could be mentioned—hypersonic tunnels, shock tubes, turbo-jet, ram-jet and rocket ground test rigs and so on. There is, however, one development, not specifically aeronautical, which is exerting an increasingly powerful influence on the work of the firms and the research establishments; I refer to the appearance on the scene of massive digital and analogue computers.

Such apparatus enables mathematics to be clothed with arithmetic in a manner undreamt of a few years ago. The number of degrees of freedom which can be handled successfully in flutter calculations has been increased enormously; theory can be applied much more rigorously to structural stressing and stiffness problems; theoretical aerodynamic derivatives can be calculated in minutes rather than in months; aircraft performance estimations can cover a much wider field, and so on. This development—in Industry and the Establishments—will continue and must be encouraged up to the hilt. A word of warning is, however, needed—particularly to the younger people now entering the profession and being, as it were, thrown in at the deep end with all these vast computational resources available to them. Results of great complexity, covering a very wide spread of variables, can be obtained so readily that there is a danger—when dealing with any particular problem—of piling up such a great mass of numbers that digestion of their meaning and significance is difficult. It can only be achieved effectively by obtaining a thorough physical grip of the problem. This is best acquired by the old fashioned method of grossly over-simplifying the mathematics, ruthlessly knocking out secondary terms, and studying and physically understanding the result. Having done this, the extra terms can be piled in, the mathematics elaborated, and—with the aid of the new machines—the numbers still obtained. Unless such initial simplification is undertaken in order to get physically on top of the problem, the investigator can get into a mental fog without knowing it—and dangerously false steps can result.

PART III—RESEARCH AND DESIGN

1. Specifications

Some of the remarks in this portion of the lecture are written with my tongue in my cheek. My experience has largely been gained at the Royal Aircraft Establishment—for 10 years or so as a member of an aerodynamic flight research team, and more recently in helping to look after the activities of a number of groups of research workers, first on guided weapon problems and more recently over a more general aeronautical field. With such a background, I can imagine any thoughts of mine on design offices and their problems being greeted by my industrial friends with remarks about grandmothers and eggs. However, an onlooker sees something of the game, and over the years one has many contacts with our design organisations and is bound to develop views of one's own. Here are some of them.

Let us start with what the Aircraft designer is asked to do. Whatever it is, the customer—civil or military—will not get what he thinks he wants in the way of a finished product for a number of years; Air Commodore Banks has argued in a recent lecture to the Society* that this period should be nearer five than ten years. Now much can happen in five to ten years, so before the designer can be given a specification a great deal of peering into a rather cloudy crystal ball must be done by someone. First of all the job to be done in five to ten years time must be established—this in itself is extremely difficult and often problematic in detail. Then likely and economic methods of doing the job must be examined, not purely in the light of existing information but also bearing in mind additional knowledge which might come from current research programmes during the next few years and which might be fed into the design. Feeling around all this, the customer and his advisers come to the conclusion that it would not be unreasonable to ask the Industry to produce an aeroplane or missile of certain specified advanced characteristics—in terms of speed, altitude, rate of climb, manoeuvrability, payload, equipment, economy and the rest, depending on the job to be done—and the Chief Designer and his team are asked to get on with it.

One cannot over-rate the importance of doing this preliminary "assessment" work—leading to some sort of specification for an aircraft or a "weapon system"—responsibly and thoroughly. One cannot also over-rate the importance of *not* blinding oneself with science at this stage and coming out with some "optimum" solution to which the design team is rigidly screwed. If a problem is set up—say the most efficient way of intercepting and destroying x aeroplanes coming in at a definite spacing in height, plan position, and time—it is possible with modern computational machinery to extract all sorts of optimum solutions which are cast iron, provided that the numerous basic assumptions made are right. They never are. As I see it the importance of this work is not to give definite numerical answers. It is to give a group of people an instinctive "feel" of the problem—an understanding of which parameters are of great importance and which are of little moment (this cannot be gained just by common sense); and of the way in which the major parameters interact one with the other. Only with such a background can responsible advice be given to the customer on the most profitable way of spending his money.

*The Importance of Time in Aircraft Manufacture, F. R. Banks, *Journal of the Royal Aeronautical Society*, January 1957.

As soon as a design team is selected they must be given full access to this preliminary "assessment" work; indeed, there is considerable virtue in the team doing a lot of it themselves. In a competitive world, however, there is obviously merit in the early stages in having an organisation independent of any particular firm, well versed in doing such preliminary assessment of costly aircraft and weapon systems; an organisation which can work intimately and informally with the customer—with much to-ing and fro-ing of ideas—in helping to hammer out the sort of task industry should be asked to undertake. An assessment team of this sort must have close access to the various aeronautical research groups, in order to obtain a clear view of the flow of new ideas coming along. The point I want to make here is that, when a specification finally gets out to industry, as a result of such preliminary work, its details should be considered as a helpful guide rather than as a completely rigid framework. The dominating thing must be the operational task which the customer wants to undertake at a certain date.

2. Weapon Systems

A design competition having been held, and a firm or group of firms selected for the task, we now run head on into the "weapon system" concept—the idea that in the case of, say a fighter, the airframe, engine, armament, airborne electronics, equipment, communications, ground environment, and so on, are all of equal importance; and that ideally a Chief Designer should have a grip of the whole lot in order to tailor all these components together into a coherent project which does the job required in an efficient way, and—very important—in which datewise all these components pop up for integration at the right part of the development programme.

There is, of course, a lot of sense in this, provided that it is not taken too logically and rigidly. The uncharitable may say it springs from the picture of the gifted aeroplane designer, soaked in aerodynamics, rate of climb and top speed, who hires a good stress man, knows an excellent engine firm which will give him something off the shelf, and produce a really beautiful aeroplane with superb flying characteristics; a thing of beauty and a joy forever—until some vulgar fellow starts wanting to spoil it by putting in guns, radio sets, and A.1 dishes.

This is possibly a somewhat overpainted picture. The designer can usually counter jibes of this sort with biting remarks about the junk served up to him to put in his aeroplane—stuff over which he has no control and which, in his view, is usually too big and too heavy for the job it is alleged to do. To my mind the whole essence of the "weapon system" concept is in giving the Chief Designer *responsibility* for as much of the system as is practicable. Quite obviously, the line has to be drawn somewhere—certain items cannot be completely tailored to each aeroplane; pilots do not want widely different flight instrument presentations and layouts; there may be virtue in standardising certain items of ground gear; and so on. But each of such things should be considered on its own merits, and every effort made to load on to the design team as much responsibility as it can sensibly carry.

This means that the Chief Designer must have senior men covering a very wide diversity of technical skills—even if he sub-contracts heavily to specialist firms. He must have people under his direct control who can talk to the specialist firms in their own terms, but who also have in front of them continually the problems of integrating their items with the rest of the system.

So far so good. The "weapon system" concept tends to go wrong, however, if planning is over-rigid and if enough allowance is not made for changes in techniques and ideas during the evolution and development of the system. The whole essence of a good system is elbow room for change. Advantage must be taken of pleasant surprises—engines coming up with more power, new electronic techniques which make obsolete earlier thinking, and so on; allowance must be made for reverses—as for example the specified accuracy of some component turning out to be physically unattainable, or flight behaviour not lining up with prediction from the tunnels because of some obscure scale or aeroelastic effect. A brittle system is a bad system.

It is unfortunate that, as mentioned earlier when dealing with design sensitivity, supersonic aircraft will —at least during the first generation or so—give the designer less scope for manoeuvre than he would like. Nevertheless, the basic principle remains. Some elbow room must be preserved during development if something good is to come out in the end. But the designer must guard against too much chopping and changing—the elbow room must be used wisely. A final sobering thought—and possibly the greatest argument for flexibility—is that, at the end of the day, the job that the system will finally be asked to do is quite likely to differ in detail from that envisaged when work was started some years before; time does not stand still.

3. The Tie-up Between Research and Design

It would, I suppose, be possible to run a research establishment in which the scientists got all their professional information through their "in-tray," by letter and publication; and let loose the results of their researches in reports, notes and memoranda written quickly at the behest of a tough management. I would hate to work in such a place.

The essence of a lively research activity—particularly in aeronautics where much research is of the applied variety—lies in *personal* contact between the individual scientist and those interested in what he is doing. Of course his work must be written up, but if what he has done is good and has any bearing on the problems he knows are facing a design team, he ought to get together with his opposite number in the design team and proceed to sell his wares. At the R.A.E. we do an immense traffic of this sort, and find discussions with our colleague in Industry and at the universities of immeasurable help. Very often a new twist is given to the work as a result of such contacts, or the final report is modified because of a different slant provided by the ultimate user.

At various times there have been many discussions on the relative volume of "pure" and "applied" research which could be done at an aeronautical establishment. Unless one is careful, such discussion degenerates into an argument about the meaning of words—"pure" being a term of peculiar difficulty. As I see it research in aeronautics can be carved up into three very rough classifications:—

(*i*) *"Ad hoc" research.* Obtaining new knowledge about the behaviour of something already designed in fair detail. A good example is the test in a wind tunnel of a specific aeroplane model, the full scale machine possibly being half built but the designer wanting detailed information as a prelude to the prototype trials.

(*ii*) *Applied research.* Obtaining new knowledge in aid of some quite firm objective or requirement, preparatory to detailed design work being undertaken.

(*iii*) *Pure research.* Obtaining new information, in a field which you think might be useful, with only a rudimentary idea of what people are going to do with the information once it is obtained.

It may be said that Industrial research tends towards the "ad hoc" variety, while the Universities are more "pure," the official Establishments occupying a middle position. While there is some truth in this, generalisation can be dangerous. The Aeronautical Industry is doing an increasing amount of applied research, as are the Universities. In a large government establishment there is great merit in having a finger in all three pies.

When dealing with a very mixed research field, from pure to *ad hoc*, in my experience it is a very good thing for the scientists themselves not to pay too much regard to such labels, and for their individual work to vary in character from time to time. A man dealing with the intricacies of boundary layer behaviour under flight conditions not likely to be achieved for many years to come, benefits greatly by occasionally turning his attention to some boundary layer problem of the moment which is worrying designers; someone who does a certain amount of *ad hoc* wind tunnel testing for Industry gains by changing every so often to a generalised programme on research models designed to pave the way for the designs two or three generations ahead. This applies particularly to the younger workers during the formative stages of their careers.

I feel that it is a sound policy for an aircraft firm to build up quite sizeable wind tunnel, structural test, flight test, and computing facilities for its own *ad hoc* work. It is clearly economical to concentrate the largest and most expensive facilities in central establishments, gear so costly that no individual firm could justify the capital outlay solely for its own work; and for these facilities to be used by the firms. Such very large facilities—be they wind tunnels or missile ranges—must therefore carry quite a heavy load of *ad hoc* work on behalf of Industry. It is, however, important that the pressure of *ad hoc* work on these massive research tools should not crowd out the equally important applied and pure research programmes which rely on them to provide key check points; in managing such facilities one must always be on one's guard to avoid the natural emphasis on urgent problems of the moment gradually leading to an ever-shrinking volume of the longer term work which gives us all our scientific capital for the future.

When considering the fostering of good working arrangements between research establishments and the design teams in Industry, one matter which can cause untold trouble is "design responsibility." In dealing with the weapon system concept earlier on I mentioned that its essence was the loading of the Chief Designer with as much responsibility as is practicable. One of the functions of a research establishment should be to advise—to provide a high grade consultancy service to the designers, who should be free to accept or reject such advice. With aircraft we have all been used to such a system for many years. However, when some specialised articles of equipment are needed which represent big advances in technique, there is a natural tendency to feel that the research people who made these advances should carry some design responsibility while Industry is being indoctrinated and becoming familiar with the new art. Under the pressure of an urgent project date, this may be inevitable, but the sooner responsibility can be put where it really belongs, the sooner will healthy design teams spring up in Industry. A bold early policy in this respect can pay handsome dividends. Should a research group be saddled with design responsibility for too long, sooner or later it is bound to find itself in competition with Industry; as soon as this happens its effectiveness as a consultant agency is largely lost.

This is a perfectly general point, applying not only to the relationship between Government research groups and design teams in Industry, but to the cross linking of any research organisation which provides a consultancy service with any design organisation making use of such a service. Unless the design organisation has power of decision, it will never become first rate; if the research organisation is narrowed down to the detailed problems of a few dated projects, it can quickly cease to be first-rate.

4. Specialisation

Aeroplanes, missiles, weapon systems—all demand in their conception large numbers of high grade men each with a good grasp of a wide variety of skills, in order that the activities of hosts of highly specialised groups shall be properly brought together. How are such men to be trained? In the specialist groups themselves, many men will establish their utility and reputation in their own intricate and complicated subjects, and will remain specialists all their lives. Is there a danger of them becoming too narrow minded, and how is this to be avoided?

These questions have, I believe, become acute in aeronautics since the war. In the 'thirties, while of course we had our engine groups, our structures people, our aerodynamic teams, our equipment people, and so

on, the members of such teams were quite consciously part of a larger whole—they were all "aeronauts" and took a great general interest in what was going on around them. As men matured it seemed a natural thing for some of them to widen their activities, and to take on broader responsibilities; they had the "feel" of the aeroplane design business.

Since the war the number of specialist areas has multiplied alarmingly, but inevitably, and the complexity of most of them has so increased that a good man finds it more than a full-time job to keep abreast of his subject, with little time to spare in finding out what his colleagues in other fields are doing or why they are doing it. In many areas the rate of progress is so rapid that, when he can get away to conferences and symposia, he gives priority to those on his own subject attended by fellow specialists.

In my judgment there are all the elements of an unhealthy situation building up here, particularly for the younger generation now entering aeronautics. A few points for debate are:—

(*i*) Before a man enters aeronautics, from the University or a Technical School, let him be given a broad training in fundamentals, rather than intensive training in one small corner of applied science. To my mind the virtues of learning "on the job" are nowadays rather under-rated, and I have an uneasy idea that educationalists tend to make their charges specialise too young. A man who "learns on the job" in the firm or the Establishment may not be as useful during the first few years as a more highly trained specialist entrant, but may be just as good subsequently and be more likely to broaden out as he gets older.

(*ii*) All organisations dealing with large numbers of professional people, such as firms, research establishments, and learned societies, face the problem of organising informal or formal get-togethers of members of the profession at meetings, debates, lectures, and so on. Is too much attention paid to getting specialist groups together for talks among themselves? One feels that this will happen anyway, and should require the minimum of forcing. Should not more attention be given to arranging, say, for a group of aerodynamicists to be addressed by an electronics man; or for the servomechanisms people to listen to a structural expert? I am in no way decrying the activities of specialist groups and specialist lectures, but do feel that cross-fertilisation of ideas and techniques is of great importance; and that unless we stress and encourage this, our aeroplanes and missiles will not be as good as they ought to be.

(*iii*) The evolution of the leaders of our design teams—and of our research teams—needs careful watching. If a man gets particularly good in his own specialist line during his early days, there is a very human tendency to keep him doing what he is doing—since first rate men do not grow on trees. A conscious act of policy is needed to move such a man to a new sphere of work, thereby getting an immediate loss in the strength of one's effort, in order to reap a future gain. Career planning of this sort is essential for the future health of aviation.

5. Detailed Engineering

The basic principles of good sound engineering practice remain unchanged, and are as important as ever. It is imperative that this simple fact should not be glossed over owing to our increasing involvement in the scientific intricacy of modern systems. When we have finished with our optimisations, our cunning feedbacks, limiters, and the rest, we end up with a series of component parts each of which may have a simple and well defined job to do. Just as much care and attention must be given to the detailed design of these component pieces, doing quite humble and mundane tasks, as to the overall system. An electrical switch, which only has to be firmly either "off" or "on," could—if defective—jeopardise an aircraft in certain circumstances just as certainly as a major aerodynamic or structural weakness.

It may be platitudinous to draw attention to this, but I make no apology for it. There is much more to the design of a small and apparently simple component than meets the eye. Environmental conditions—temperatures, pressure, vibration limits—must be established with a good tolerance for error; the specification must be well conceived; above all—be the component mechanical or electrical—an experienced mechanical designer must play a part in its evolution; care must be taken over the schedule of tests it must pass before getting into the aeroplane; production and inspection techniques need watching, as do questions of storage and life. "Take care of the pence and the pounds will take care of themselves" may well be an over-statement as applied to aeroplane design. But the pence—in the shape of the hosts of small details—are certainly just as vital as the pounds.

6. In Conclusion

Looking at the aeronautical scene in the round, one cannot help being stimulated by the challenge of the future. So far we have only scratched the surface, and several generations may pass before the full potentialities of aerial locomotion are appreciated.

Already we can see ahead vastly extended speed and height brackets, new approaches to the problems of take-off and landing, and changed power plant conceptions. The things we now believe to be firmly within our grasp would have seemed fantastic 20 years ago.

Designers and research workers will forge an ever-stronger partnership in the years ahead. Our activities are increasingly complementary as the pace of advance steps up. While we all have our local loyalties, I like to feel that we have a wider loyalty to Aviation. At the moment British Aviation is firmly on the map; with plenty of hard work we can help to keep it there.

The Problems of Jet Transport Operation*

by

J. T. DYMENT, B.A.Sc., F.R.Ae.S., M.E.I.C.
(Chief Engineer, Trans-Canada Air Lines, Montreal)

ALL OF US who are intimately connected with aviation appreciate that the introduction of a new era of air transportation—the jet age—will not be accomplished without a tremendous effort in almost every field of the Industry.

There are current problems for which solutions are available but not implemented, current problems requiring new solutions, and new problems associated with the unique characteristics of the jet aeroplane.

We are confident, however, that the problems facing the Industry can, and will, be overcome in time to begin jet services as planned. This is not just wishful thinking because the magnitude of the situation was appreciated by most of the airlines before ordering the new jet transports. Each airline at least had an idea in its mind of how to get around a problem in case it was not solved to its satisfaction in time.

Why should there be problems in introducing turbo-jet transports within the next two to three years, in view of the wide background of experience the airlines have accumulated with large reciprocating-engined aeroplanes and small propeller-turbine aeroplanes?

It is appreciated that one airline in the world—B.O.A.C.—has acquired a wealth of turbo-jet aeroplane experience; but even B.O.A.C. will face the same problems as everyone else in 1960. B.O.A.C. will merely have more of a background to help solve them.

To answer the question: let us first summarise a few of the major differences between the transports we expect to operate in 1960 and the transports most of us are using today.

Speed—The new jets will cruise at speeds between 550 and 600 m.p.h. compared with current speeds between 325 and 350 m.p.h. This feature alone creates a host of new problems in Air Traffic Control, Communications, Cockpit Design, and so on.

Fuel—The new jet transports will consume fuel at a rate between 10,000 and 15,000 pounds per hour, compared with 2,000 to 3,000 pounds per hour for current reciprocating-engined aeroplanes.

Noise—Although one cannot make a direct comparison, the relative noise level of a free jet engine would be 120 db. compared with 110 db. for a reciprocating engine under similar conditions.

Take-off—The power available from the engine of a jet transport falls off much more rapidly than from a reciprocating engine as the ambient air temperature rises. It is generally not obvious by feel that something is wrong and that an engine is not producing its full thrust.

Cruising—Since the jet engine is so sensitive in fuel consumption to any departure from the ideal operating condition, it is desirable that the aeroplane always be flown at as high an altitude as possible compatible with its weight and the prevailing ambient air temperature.

Landing—The pure jet aeroplane so far has had nothing comparable to a propeller to assist the wheel brakes in stopping it quickly during a landing.

Rotating Parts—Because of the magnitude of the harnessed energy in the turbine and compressor wheels when rotating at speeds of 15,000 r.p.m., they must be treated throughout their entire service life with even more respect than has been necessary with components of reciprocating engines to avoid failures.

Size—With the increased power available from turbine engines, the weight of transports will be double that of today (300,000 lb. against 140,000 lb.) and there will be almost twice as many passengers to look after for each flight (122 against 63, 140 against 74, and so on). The size also permits sufficient fuel to be carried to enable the North Atlantic region to be operated non-stop between major cities.

Table I illustrates the differences between the aeroplanes T.C.A. will have by the Spring of 1961, by which time its entire fleet will be Rolls-Royce turbine-powered, and its previous fleet of reciprocating-engined aeroplanes. Viscounts are already replacing DC-3's. The first DC-8 is expected from Douglas in December 1959 and the first Vanguard from Vickers-Armstrongs in September 1960.

Table II illustrates runway length requirements of a typical intercontinental jet transport—the Douglas DC-8.

Table III illustrates the flight characteristics expected at the present time from its turbine fleet. It must be remembered that aeroplane characteristics change continually. Engine developments are already transpiring, sooner than originally expected, which will further improve the aeroplane's performance.

*A Lecture given before the Weybridge and London Airport Branches of the Society in March 1957.

	1961 TURBINE FLEET			LAST RECIPROCATING ENGINED FLEET		
	VISCOUNT	VANGUARD	DC-8	DC-3	NORTH STAR	SUPER-CONNY
A/C MFR.	VICKERS-ARMSTRONGS		DOUGLAS	DOUGLAS	CANADAIR	LOCKHEED
A/C TYPE	724/757	952	DC-8	DC-3	M2-3/-4	1049E,G
GROSS WEIGHT.LB.	60,000	141,000	287,500	26,200	79,575	135,400
LANDING WEIGHT	54,000	114,000	190,500	26,000	72,000	113,000
ZERO FUEL WEIGHT	49,000	104,500	167,250	-	68,000	103,500
OPERATIONAL WT.EMPTY	37,500	79,000	131,800	18,370	50,200	81,000
WEIGHT LIMITED PAYLOAD	11,500	25,500	35,400	-	18,127	22,500
WING SPAN	93'-8"	118'	134'-9"	95'-0"	117'-6"	123'-0"
WING AREA - SQ.FT.	963	1,529	2758	987	1457	1654
OVERALL HEIGHT	26'-10"	34'-11"	42'-4"	16'-11"	27'-7"	24'-9"
BODY LENGTH	81'-2"	122'-10.4"	140'-6"	64'-5"	93'-10¼"	113'-7"
BODY WIDTH, OUTSIDE	10'-8"	11'-6"	12'-3"	8'-1"	10'-5"	11'-7"
BODY DEPTH, OUTSIDE	10'-8"	13'-7.15"	13'-6¼"	8'-6"	11'-6"	11'-7"
BODY - GROUND CLEARANCE	3'-9"	3'-6"	6'	-	6'-1"	7'-4"
PASSENGER CAPACITY - FIRST	44	82	122 MIN.	21	48	63
TOURIST	(48)	121	162 MAX.	28	62	81
CARGO COMPTS. VOL.CU.FT.	550	1,360	1415	164.4	478	659
SPACE LIMITED PAYLOAD LB.	14,070	35,410	42,930		15,920	19,000
ENGINE MFR.	R.R.	R.R.	R.R.	P & W	R.R.	WRIGHT
ENGINE TYPE	DART RDa3	TYNE 11	CONWAY RCO10	R-1830	722/724	R-3350
TAKE-OFF POWER	1540 ESHP	5315 ESHP	16,500 LB.	1200	1,760	3,250
FUEL CAPACITY IMP.GAL.	1950	5100	18,100	670	2,358	5,452
MAX.RANGE STAT.MILES	2060	3500	6,500	1465	2,150	3,900
PAYLOAD AT MAX.RANGE	7715	23,270	16,050	2100	13,000	16,500
RANGE AT MAX.PAYLOAD	1470	3,250	5,330	275	1,680	3,920
RUNWAY FOR GROSS T.O.,FT.	5000	6,400	9,000	4,470	5,800	6,100
RUNWAY FOR LANDING	5300	5,500	6,700	3,580	5,320	5,700
APPROACH SPEED	120	138	151	95	115	130
TCA NORM.CRUISE SPEED	314	425	550	171	230	293

TABLE I.

AEROPLANE CHARACTERISTICS IN T.C.A. FLEET

① AIRPORT	② DESTINATION	③ ALTITUDE	④ AVERAGE SUMMER WIND KNOTS	⑤ TAKE-OFF WEIGHT	⑥ TAKE-OFF RUNWAY LENGTH STD.	80°F	90°F	⑦ LANDING WEIGHT	⑧ LANDING RUNWAY LENGTH STD.	80°F	90°F
VANCOUVER	LONDON	35000	+28	287500	9000	10400		190500	6700	6960	
CALGARY	TORONTO	30000	+28	229000	6850		8450	190000	7550		8190
EDMONTON	LONDON	35000	+28	284000	10250		12500	190500	7200		7750
TORONTO	LONDON	30000	+28	281000	8800		10850	190500	6750		7210
MONTREAL	LONDON	30000	+28	274000	8100		9950	190500	6700		7130
PRESTWICK	TORONTO	35000	-35	286000	8900	9500*		190500	6700	6850*	
LONDON	TORONTO	35000	-35	287500	9000	10400		190500	6700	6960	

*CALCULATIONS AT PRESTWICK FOR HOT SUMMER DAY BASED ON 68°F

LANDING R.W.L. SHOWN IN COL. ⑧ FOR AIRPORTS IN COL. ① BASED ON FLIGHT FROM AIRPORTS IN COL. ② MAR. 6, 1957

TABLE II

RUNWAY LENGTHS FOR DC-8 AIRCRAFT

	VISCOUNT	VANGUARD	DC-8
TAKE-OFF, WEIGHT: LB.	60,000	141,000	287,500
FLAP SETTING: DEG.	20	20	25
V_2 SPEED ($1.15V_S$): KNOTS	112	129	151
LEVEL OFF TO ATTAIN CLIMBING INDICATED AIRSPEED OF: KNOTS	180	170	290
CLIMB AT THIS IAS TO ALTITUDE OF: FT.	18,000	20,000	27,100
AVERAGE RATE OF CLIMB: F.P.M.	750	1,200	1,700
CONTINUE CLIMBING TO INITIAL CRUISING ALT. AT A T.A.S. OF: KNOTS	-	-	450
INITIAL CRUISING ALTITUDE DEPENDING ON WEIGHT: FT.	-	-	32-35,000
CLIMBING CRUISE T.A.S. AT 1.19 L/D:	-	-	476 @ 195,000 LB. 482 @ 280,000 LB.
MAXIMUM ALTITUDE: FT.	-	-	40,000
DESCENT, LONG RANGE PROCEDURE T.A.S.	-	-	480
DOWN TO ALTITUDE OF:	-	-	36,000
THEN CONTINUE DESCENT AT I.A.S.	-	-	260
DOWN TO ALTITUDE OF:	-	-	1,000
RATE OF DESCENT - LONG RANGE: F.P.M.	-	-	1,700
NORMAL: F.P.M.	2,000	25-3,200	4,000
EMERGENCY: F.P.M.	7,000	-	-
CIRCUIT & MANOEUVRE AT $1.3V_S$ I.A.S. KNOTS:	140,130	130	143
WITH FLAP SETTING OF: DEG.	20	20	15
FINAL APPROACH AT $1.3V_S$ I.A.S. KNOTS	120	120	131
WITH FLAP SETTING OF: DEG.	40	40	50

TABLE III

IDEAL FLIGHT PROCEDURES—T.C.A. FLEET

The Airport

The enlargement of railway stations and ship docking facilities occurred gradually over a 100-year period. The proportional enlargement of airports and air terminals has occurred in less than 20 years. The prospect of there being a need for bigger rail and ship passenger accommodations than now exists, is fairly slight while the expansion of air travel is occurring at such a rate that it takes an extravagant amount of accommodations today to avoid being saturated by traffic in less than 10 years.

The adequacy of the airport facilities, to accommodate the types of turbine transports that will be available in the 1960's, is entirely up to the local authorities. If they wish their community to be served by the new transports they must see that their airport facilities are adequate.

There are new requirements due to the characteristics of the turbine engine, but the requirements that will cost the most are due chiefly to the simple fact that the new aeroplanes will be larger in order to accommodate the increasing traffic.

History has shown that each generation of aeroplanes has been larger and faster than its predecessor. Runway lengths and strengths, and passenger handling facilities, have had to be continually increased. We are coming to one more step whose cost will depend upon the vision, or lack of vision, displayed in the design of the previous airport facilities. It has been estimated that only about five per cent of the world's international airports are at the present time satisfactory for the needs of the turbine era.

Airports today should be designed and financed by people with vision beyond the ordinary.

RUNWAYS

In addition to having to provide stronger and slightly longer runways at many airports, there will have to be a wider use of concrete. It is desirable, for ruggedness and clearness of markings, that the first thousand feet of each runway be concrete. Concrete is also required at re-fuelling points and at ramps (aprons) where fuel spillage might occur and damage asphalt base surfaces. At the same time it should be mandatory for all turbine power-plants to be equipped with a reservoir to catch fuel spillage from the engine itself.

CLEANLINESS

More adequate housecleaning equipment will have to be provided than is now generally used; airport authorities will have to maintain a continual policing of runways, taxi-ways and the ramp, to prevent foreign objects or loose sand on the surfaces being sucked up or thrown into a turbine engine. It is not practical to equip the engines with intake screens.

SNOW AND ICE

The handling of snow and ice will require considerable thought. The application of hot sand to an icy surface will no longer be a desirable procedure, nor will the continued application of calcium chloride likely be accepted by the airlines. The absence of propellers has permitted smaller ground clearances, so even more corrosion will be experienced with under surfaces than today, unless airports are prohibited from using corrosive salts.

VISUAL AIDS (*See* Figs. 1 and 2)

The increased final approach speed of jet aeroplanes accentuates the need for improvements in the visual aids which have already been requested for current aeroplanes. The better the aids, the lower may be the safe visibility limits, and hence the better the regularity of the service. The approach, threshold, and runway should be treated in such contrasting fashion that at no time could one be mistaken for the other two, whether visible or not. Identification must be instantaneous and instinctive. Complete agreement as to the best way of accomplishing this has not yet been reached but all agree that the basic requirements include Identification; Alignment; Roll Guidance; Height Guidance, Distance and Positive definition.

SERVICE AREA

Since an aeroplane only makes money as long as it is flying, effort should be made to shorten the *en route* stop time and turn-around time. A parking area is, therefore, needed near the ramp, with the ability for the airline to do servicing not requiring the running of engines at this point. At the present time, at some airports, over an hour is lost in taking the aeroplane to its servicing point and returning it. Servicing requiring the running of engines should still be done as close as practicable to the ramp as determined by the effectiveness of service noise suppressors.

STARTERS

No great problems have been encountered in starting piston engines since very low cranking speeds are required to get them going.

With turbine engines, speeds of 2,000 to 3,000 r.p.m. are required before the engine is self-sustaining, and at these speeds, the compressor is absorbing an enormous amount of power. Electrical starters can be used up to a point but they demand extremely high powered ground units. On the larger engines pneumatic starting has been found to be the most practical.

The problem is: which way is best to provide a large volume of high pressure, high temperature, air? An auxiliary turbine unit would appear to be the logical choice but existing turbine starting units are noisy and a nuisance on the ramp. Perhaps a hydrant system could be used at the larger airports, but the development of adequate silencers will still be necessary to permit the general use of turbine starters.

HYDRANT SYSTEMS

Because of the high rate of fuelling required (over 800 Imperial gals./minute) for the new big transports, and the desire to avoid using large vehicles on the ramp, fixed fuelling hydrants are necessary. Similarly, to hold the number of vehicles required on the ramp to a

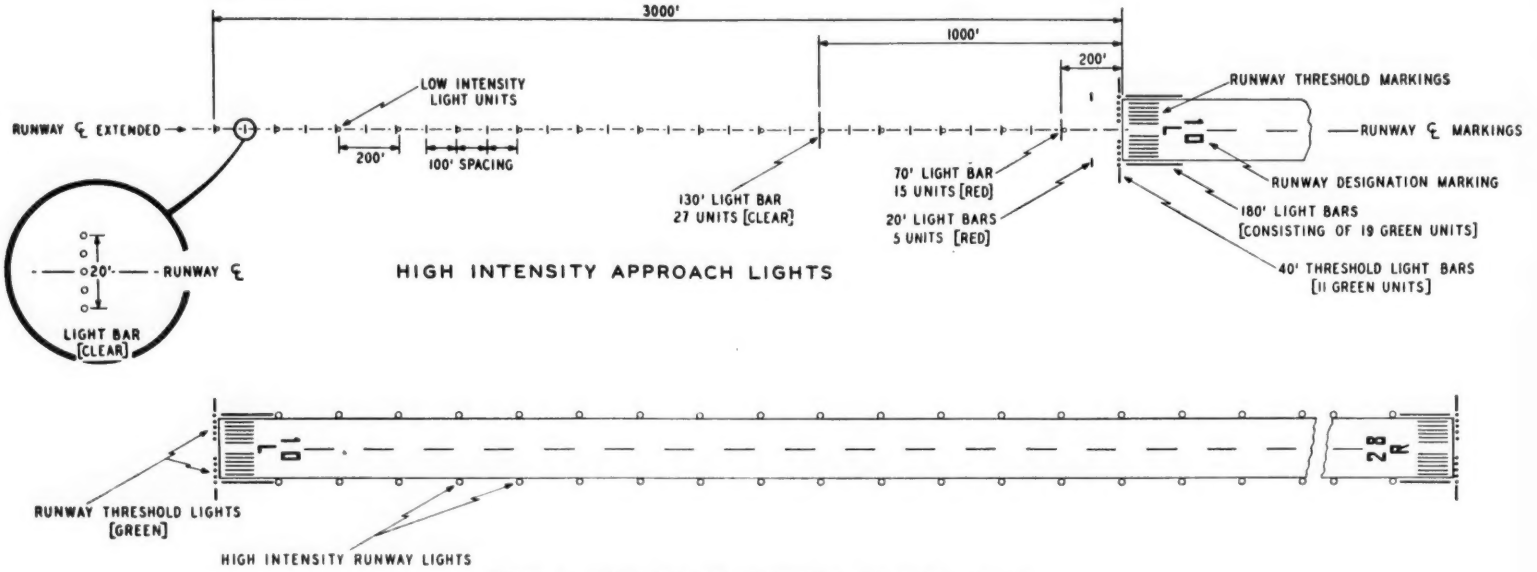


FIGURE 1. Civil visual aids to approach and landing—Canada. Instrument runway. Marking and high intensity lighting configuration.

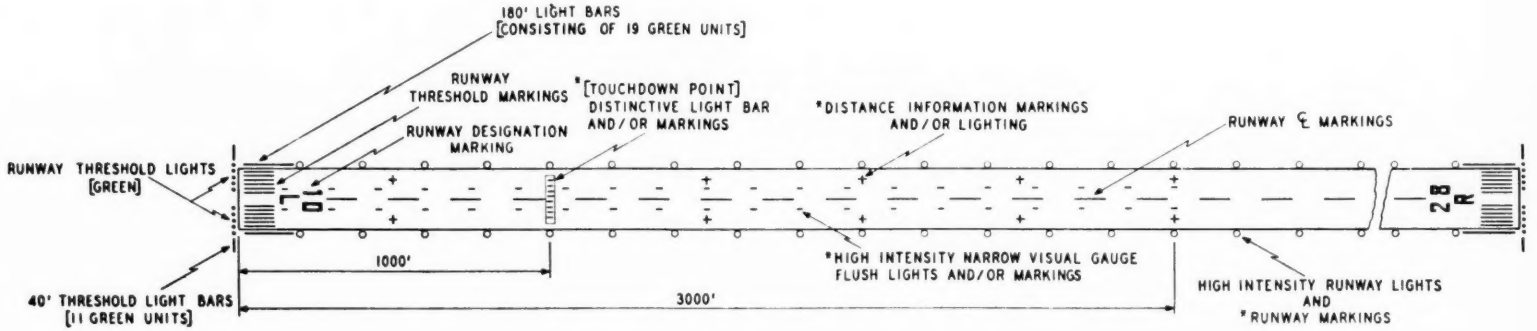

180' LIGHT BARS [CONSISTING OF 19 GREEN UNITS]
RUNWAY THRESHOLD MARKINGS
RUNWAY DESIGNATION MARKING
*[TOUCHDOWN POINT] DISTINCTIVE LIGHT BAR AND/OR MARKINGS
*DISTANCE INFORMATION MARKINGS AND/OR LIGHTING
RUNWAY ℄ MARKINGS
RUNWAY THRESHOLD LIGHTS [GREEN]
10
28 R
1000'
*HIGH INTENSITY NARROW VISUAL GAUGE FLUSH LIGHTS AND/OR MARKINGS
40' THRESHOLD LIGHT BARS [11 GREEN UNITS]
3000'
HIGH INTENSITY RUNWAY LIGHTS AND *RUNWAY MARKINGS

FIGURE 2. Additional visual aids to flare and landing proposed by I.A.T.A. Instrument runway.

minimum, fixed facilities are also desired to provide electricity, conditioned air, compressed air, and sewage disposal.

TAXI-WAYS

Because of the high fuel consumption of a jet aeroplane during taxying and idling (up to 10,000 lb./hr.), the airport layout should be such that taxying time will be held to a minimum. Access to the most used runway should require the least taxi time. It is desirable to have high speed turn-offs and turn-in, to clear runways as quickly as possible for other aircraft landing or taking-off. To permit this, a taxi-way turn radius of around 750 feet should be satisfactory.

TAXI-WAY BY-PASS AREAS

Although taxi-way by-pass areas are needed today to permit an aeroplane held up for any reason to stand off the taxi-way, it is even more important that they be available in time for jet aeroplane operations.

TAXI-WAY SHOULDERS

Because the outboard engines of the big new transports will extend beyond the normal 75 foot wide taxi-ways, some means must be evolved, whether it be a hard surface or a tough type of grass, to prevent erosion at the sides of the taxi-ways and to prevent damage that might result to an engine of a following aeroplane from the lifting of debris or dirt.

RAMP BLAST FENCES

At the present time, it is believed that blast fences five or six feet high might be required on the ramp behind which personnel can slip (as a bullfighter in a ring) for protection against the jet blast and noise when high power is used by the aeroplane to start it moving. The break-away thrust requires around 80 per cent maximum r.p.m. Apart from these few moments when the aeroplane first starts rolling, no real problem is expected from either blast or heat from civil jet engines.

SPEED-UP OF GROUND TIME

Because the new transports will be carrying around 120 to 140 passengers, and because several aeroplanes can arrive or leave almost simultaneously, the entire passenger handling procedure and accommodations are in great need of review.

Millions of dollars are being spent to reduce the time it takes to fly from one airport to another, but relatively little progress has been made so far to reduce the time it takes between leaving one's home or office and sitting in the aeroplane. It has been said that we are living in a wonderfully progressive age. "We'll soon be able to fly from any place in the world to any other place in almost the same time as it takes to go to and from the airport."

Providing through-ways or super-highways from downtown to the airport, or re-locating the airport to be on such highways, can be a fabulously costly business. Only long-range planning can solve the problem of transportation time to and from airports.

AIRCRAFT HANDLING AT RAMP

A great deal can be done to speed up the handling of passengers through an airport. This could begin with how best to handle the aeroplane and its load on the ramp.

A jet aeroplane can be handled in exactly the same manner as reciprocating-engined aeroplanes—that is, they can taxi in under their own power, turn around, come to a stop, discharge passengers and cargo as today, be serviced, reload and taxi away under their own power. There might be a better and faster way of doing these things.

One view is that the aeroplane should taxi to the vicinity of the ramp, stop its engines, and then be towed into a dock position, serviced and towed out to a particular spot where the engines could be started and the aeroplane taxi away. This method would result in a minimum of noise at the ramp, but it could be too slow unless better means of handling large aeroplanes are devised than exists today. The lack of traction when towing on a slippery surface accentuates the problem. Even under non-icing conditions the tractor would have to weigh around 30 to 40,000 lb. and have a draw-bar pull between 20 and 30,000 lb.

Another suggestion that merits considerable study is that the aeroplane should taxi directly into a nose dock with about six foot clearance all around the aeroplane. Movable covered extensions from the fixed ramp or dock would bridge the clearance to the aeroplane's doorway. The aeroplane could then discharge its passengers or embark them under cover and without steps. Fixed servicing facilities could all be established so that there would be a minimum of hose lines, connecting electrical lines, and so on. The aeroplane could be drawn back from the dock by a quickly connectable cable attached to a fixed capstan in the ramp, or to a power-driven capstan on a truck which itself could be quickly anchored to a fixed position on the ramp. The jet engines could be started either at the dock or after the aeroplane is pulled back. It would only be pulled back until it had sufficient room to turn and taxi away under its own power.

Another suggestion is that the aeroplane would be stopped as convenient a short distance from the passenger terminal and a long telescopic covered bridge or marquee would then move out to the aeroplane for the use of the passengers. A conveyor belt system would move into place for the loading and unloading of cargo. This method is likely to be more costly than others suggested and the marquee and conveyor belt would restrict the free movement of vehicles around the aeroplane.

Of the four methods (and there are many others), we believe that the first and third are the most practical. Where it is possible to do so, taxying the aeroplane straight into a nose dock attached to the terminal building is the most desirable; but where it is not practicable to have the necessary servicing facilities in the terminal nose dock, the conventional method of taxying and swinging around and stopping near the terminal will most likely be used at the majority of airports.

BAGGAGE HANDLING

In the latter case, the handling of passengers, baggage and cargo in inclement weather remains a real problem, as does the speedy handling of baggage, regardless of weather.

Some airlines are planning to handle their baggage in containers that can be transferred between the truck and the aeroplane by rails. Considerable cargo compartment space is lost by this method to provide clearances for the rails and containers.

Others are planning to use a long conveyor belt system that can be run out to the aeroplane. Our calculations do not confirm that unloading can be speeded up by this method.

T.C.A. is considering the use of a mobile conveyor-belt unit similar to that used extensively today for loading and unloading high compartments, but the unit would comprise three belts which could be moved sideways on the vehicle so that each belt could be presented in turn to the baggage compartment opening. The combined capacity of the three belts would hold the contents of one compartment. As soon as it was loaded, this unit would move quickly by its own power to the passenger baggage collecting point where it would discharge its load by the movable belts. The actual distribution of the baggage to the passengers in a matter of seconds is not an easy problem, but the automatic self-serve method used at the Los Angeles airport goes a long way towards clearing this particular problem.

PASSENGER HANDLING

The handling of passengers within most terminal buildings today is far from adequate to take care of the numbers that will have to be handled speedily in the future.

An intensive analytical study by the airline is sorely needed as to what it is trying to accomplish and what it needs to achieve its objectives. A time and motion study of existing terminal procedures and of mock-ups of proposed facilities, and greater familiarisation of the architect with the day-to-day problems at a terminal, are all essential to evolve a design, or re-design, that will be satisfactory for the coming traffic.

It is obvious that many airport terminal buildings will have to be remodelled immediately, or new ones built between now and 1960 or '61, or the building facilities will become the bottleneck in this modern era of mass high speed transportation. In analysing future requirements, provision should be made for continual expansion. It appears inevitable that within the next 20 years, long haul rail passenger-traffic will become just about extinct, at least on the American continent.

Another small but important point in relation to terminal design is that, if the civil operators continue to use kerosine rather than JP-4 as a fuel, the building will have to be air-conditioned because the windows on the ramp side must be kept closed to keep the kerosine fumes out. The air conditioning intake will also have to be well shielded from the fumes.

Even when up-to-date terminal facilities are provided, the human element will still remain a most important item in the speed of handling passengers through the airport. Baggage handling, Customs and Immigration, are all much too slow at some airports today. Unless a drastic revision, both mental and physical, is made these services will be subject to severe public censure in the future.

The travelling public will not take kindly to a 15-minute wait for its baggage or a 50-minute delay to get its baggage and clear through Customs after flying from some place five or six hundred miles away during the previous hour.

This problem need never arise if the Airport authority, Customs, Immigration and the airline officials work together to avoid it. I recall seeing over 450 passengers handled in 40 minutes at San Juan, Puerto Rico, a few years ago and the speed of handling was due, not to the number of officials but entirely to the enthusiasm and complete co-operative spirit that existed between the Government Airport Manager, the head of Customs, the head of Immigration, and the Pan-American Station Manager. Everyone was imbued with the idea that no one must ever be able to accuse anyone at San Juan of being slow or disinterested. They were the most efficient group I have ever seen, and demonstrated that the problem can be solved.

Meteorological Requirements

The purpose of meteorological forecasting is to enable a flight to avoid adverse weather conditions and to take advantage of favourable conditions. The new problem is that the airlines will shortly be concerned with weather up to a height of 45,000 ft., rather than only up to 25,000 ft. as we are, in general, today.

The actual "Met" information required for the forthcoming turbine era will be little different than it is today, but the penalty of not having the information at the time it is required can impose a much greater economic penalty on the airline and the travelling public.

NEW INFORMATION

Apart from the increased altitude band with which we are concerned, the new problems are to provide the airlines with a good knowledge of the velocity and boundaries of jet streams, the location and intensity of gust areas, and the ambient temperatures from sea level to 45,000 ft.

CO-ORDINATION OF INFORMATION

Safety will be more adversely affected than it is today because of the greater speed of jet transports, unless "Met" offices get together and issue the same weather information about a particular area from all points. Right now, operators using different "Met" sources for planning flights, substantially along the same track at approximately the same time, may file inconsistent flight plans because the information provided by these sources sometimes differs. As a result, initial separation between aeroplanes may be incorrectly assessed. It is essential that measures be taken to ensure accuracy and uniformity in the forecast information provided. One of the biggest problems in the "Met" field, therefore, appears to be that of developing co-ordination between all forecasting stations.

ACCURACY OF FORECASTING

The larger the fuel reserve that must be carried to cover deviations in flight plan due to changes in forecast weather, the greater will be the cost. It will be remembered that 26 gallons is equivalent to a passenger in weight, yet it will fly the aeroplane for only one minute. Accuracy in forecasting is thus even more important than it is today.

There is no place in air transport where the payload can be as easily affected as it can by calling up more fuel reserves. At the present time T.C.A. plans to start its DC-8 services carrying 7,900 lb. of fuel reserve solely as a route factor. Such a reserve is in addition to the normal reserve of 9,600 lb. for one hour's holding and 9,000 lb. for diverting to an average alternate. The total reserve is therefore 26,500 lb. which is equivalent in weight to 130 passengers.

An airline cannot run at a loss. Any cost to it will eventually be reflected in its fares.

There is one redeeming feature about jets—the elapsed time between when the forecast is made and when the weather is encountered can be almost halved from that of today.

TAKE-OFF TEMPERATURE

Because temperature has such an important influence on the take-off and climb characteristics of a jet aeroplane, accurate forecasting of initial temperature conditions is most important. Even one degree can have an appreciable effect on the permissible take-off weight and take-off runway length. The thrust output might vary as much as 20 per cent, plus or minus, from the specified rating with operation on a cold day or a hot day, respectively.

DESTINATION VISIBILITY

Similarly, because the fuel penalty involved in a missed approach (about 2,000 lb.) or a diversion to an alternate airfield is so great (9,000 lb.), it is essential that terminal forecasting of visibility under marginal conditions, such as " 200 ft. and half a mile," be most accurate. Experience of the operator with the accuracy achieved by " Met " will dictate the fuel reserves he will carry. If large, it will generally reduce the payload, and if frequent, the revenue to an extent that it will affect fares.

It is still not possible for a ground station to tell a pilot the actual visibility range he will have as he approaches a runway. Some device is needed to measure " slant visibility " as applicable to the pilot approaching for a landing.

BREVITY IN MESSAGES

Because of the increased amount of " Met " data required, particularly in the final phases of the flight, the number and length of individual messages must be reduced to a minimum. A solution would appear to be to evolve suitable codes or phraseologies.

TURBULENCE

Forecasting the location of turbulent and hail areas with consistent accuracy is desirable to avoid sudden impact with them at high speed.

The degree of turbulence associated with clouds is also desired.

Considerable research is still required into the mechanism of clear-air turbulence associated with mountain waves, in order to permit the degree of clear-air turbulence to be forecast.

JET STREAMS

Accurately forecasting the location and speed of jet streams is desirable, as previously mentioned, so that advantage can be taken of them as a tail wind, or so that the flight may be planned in advance to avoid them as head winds. Jet aeroplanes will encounter jet streams more often than present aeroplanes.

MET. WORK LOAD

It must be remembered that the " Met " people can only do so much in a given period; therefore the airlines must make up their minds on just what information is required, what is desirable and what is relatively unimportant, and then establish a priority for the information they wish passed along to them. The more they can eliminate of existing reporting, the more time will be made available to " Met " to give the airlines what they need for the jets.

If " Met " could have fewer but better equipped centres, it is likely that they would be able to give an improved forecasting service.

Air Traffic Control (A.T.C.)

Many believe this to be the toughest problem facing air transport today. The introduction of jet transports into service will only make it worse.

The objective of an A.T.C. System is to ensure a clear flight path, on a continuous and accurate basis, for an aeroplane in any location on earth regardless of weather, time or altitude. Positive separation between aeroplanes is required at all times, regardless of weather.

The major problem is that of providing " Air Traffic Co-ordination." T.C.A. uses this term " to include all aspects of planning, operation, and managing the mass movement of air traffic and includes the responsibilities of both the operators and the State authorities responsible for ensuring safety. It is this general requirement that sets the requirements for communication services, navigational aids, meteorological services, air traffic control services and operational control services. To bring Air Traffic Co-ordination into line with the development of the industry it is essential first for the administrations and the operators to agree on the general nature of the objectives and on the fundamental nature of the problem of achieving those objectives."

COLLISION HAZARD

Because of the speed of the new jets (or even current aeroplanes), dependence on visual flight conditions to avoid collision is entirely inadequate. It is completely impractical for a pilot to always see other aircraft in time to avoid a collision, even on a clear day.

Airborne Collision warning radar has been found impracticable up to the present time, and there is little

HEIGHT RESTRICTION FT.	FUEL PENALTY LB.	DISTANCE OFF BEST TIME TRACK N.M.	TIME PENALTY MIN.	FUEL PENALTY LBS.	IF AVERAGE JET STREAM INVOLVED FOR ½ FLIGHT	
					TIME PENALTY	FUEL PENALTY
2,000	400	50	5	1,000	10	2,000
4,000	1,600	100	13	2,600	24	4,800
6,000	4,400	200	41	8,200	67	13,400
8,000	7,900	TRACK ASSUMED PARALLEL TO BTT REACHED 250 N.M. FROM DEPARTURE.				
10,000	12,300					

TIME AND FUEL REQUIRED TO COVER 1000 N.M. IN A 200 KNOT JET STREAM (TAS 475K)

	EASTBOUND	WESTBOUND	DIFFERENCE
TIME	1:29	3:38	2:09
FUEL	17,800 LBS.	43 500 LBS.	25,700 LBS.

TABLE IV

FUEL PENALTIES—DEPARTING FROM IDEAL FLIGHT PLAN

hope of improvement on the basis of present knowledge. Planning an A.T.C. System must, therefore, not count on aeroplanes avoiding each other through the use of any airborne equipment alone. It is hoped that efforts will continue to be made to solve the problem of airborne collision radar, because when perfected it will provide a monitoring back-up device similar to that provided by G.C.A. during regular I.L.S. approaches for landing.

The most difficult A.T.C. problems occur in the areas where aircraft converge, or are climbing and descending, and that is what a jet aeroplane does best. It does not like to fly for long at a constant altitude. It wants to climb as it burns off fuel. This accentuates the problem for A.T.C.

IDEAL FLIGHT PLAN

For maximum efficiency, a turbo-jet aeroplane would like to take-off and climb in an unrestricted manner, as quickly as possible, to its initial cruising altitude of around 30,000 ft. (preferably climbing in the direction of its destination). It would then like to continue to climb slowly (drift-up) as it burns off fuel during cruise. At the appropriate point, depending on the distance to the destination and the altitude, it would like to descend at constant Mach number down to about 35,000 ft. and thereafter at constant indicated air speed straight into the approach for landing.

DEPARTURES FROM IDEAL

Any deviation from this ideal flight plan costs additional fuel. However, it is obvious that both traffic and adverse weather conditions will dictate departures from it. The desire is that any departure from it will be a minimum. The type of departure having the least adverse effect on fuel would generally be one in a lateral direction. Table IV illustrates some typical fuel penalties with the DC-8.

When conditions are bad or traffic is heavy and greater separation is needed, everyone cannot be permitted to make the small deviations that they might like. Undisciplined and unlimited individual freedom in the choice of flight plan would produce an unmanageable pattern and overall economy would not be achieved.

Flight planning must be accomplished in such a way that the pilot can decide rapidly whether a change proposed to his original flight plan is operationally acceptable. A.T.C. must have a full appreciation of the situations being created in order to hold all deviations to a minimum.

The ability of the aeroplane to adhere to its flight plan is directly related to the navigational aids provided, accuracy of the "Met" data supplied, and the co-ordination of control between the various Air Traffic Control centres.

ALTIMETERS

Since both lateral and vertical separations will be required, it is essential that improved altimeters be developed with much greater accuracy at high altitudes, both from the standpoint of safety and to conserve air space. Wide vertical bands for separation at high altitudes are now required because altimeters are not accurate. An accuracy is required to permit separation levels of not over 1,000 ft.

Telecommunications

Air Traffic Control is equally dependent upon the adequacy of telecommunications and electronic aids as on meteorological forecasting.

TRANS-OCEANIC NAVIGATION (*See* Fig. 3)

Long-range navigation for high speed aircraft requires rapid position fixing. This can be achieved:—

(*a*) by self-contained aircraft equipment,

(*b*) by air interpolation of ground based aids.

Since astro-navigation, at the present state of the art, is not practical, heavy concentration on the development of auto-navigational systems such as Doppler and Inertial is underway for use on long over-water flights. Such aids would replace the currently manual operated systems such as LORAN, ADF, CONSOL, and so on.

The long-range navigation system should have an accuracy such that the position fixing error will not exceed 10 nautical miles at least 95 per cent of the time.

TRANS-CONTINENTAL NAVIGATION (*See* Figs. 4, 5 and 6)

For flights over land, the short-range navigational facilities such as VOR (VHF Omni-directional Radio Range) and DME (Distance Measuring Equipment) have been used so far, but they would require continual switching from station to station with the high flying jets. A low frequency visual system will probably have to be developed for *en route* flying of the big jets with the VHF systems used for the terminal areas.

The information from all navigational systems required in the cockpit is the track and distance to go either to the destination or to points in the local area of significance to A.T.C., the altitude, and rate of change of altitude.

DESCENT CONTROL

In order that jet traffic can be co-ordinated with the aircraft at the lower levels, the whole descent path needs to be adequately defined, including the initial position of descent.

Therefore, if A.T.C. is to function effectively and use air space efficiently, there is a requirement to define in space the descent path from high altitude which can be interpreted within the aeroplane.

There is another problem in relation to holding. The jets will require a different holding area than the reciprocating-engined aeroplanes, even though they might follow the same general pattern of orbiting. The bottom of a jet stack (and we hope such a stack will seldom exist) will probably be at 20,000 ft. because the jet will burn too much fuel orbiting at a lower altitude, and at the same time it need not come lower because it can drop into the approach pattern from 20,000 ft. at a rate of from 3,000 to 5,000 ft. per minute.

Ground surveillance radar with a range of at least 120 nautical miles is desired for monitoring the descent from 45,000 ft. to touch-down, but it is considered essential for the efficient functioning of A.T.C. and to expedite the terminal area movements. Aeroplanes should all be equipped with transponders to ensure positive identification on the radar.

APPROACH CONTROL

I.L.S. (Instrument Landing System) will be required at all airports served by jet transports to give the pilot

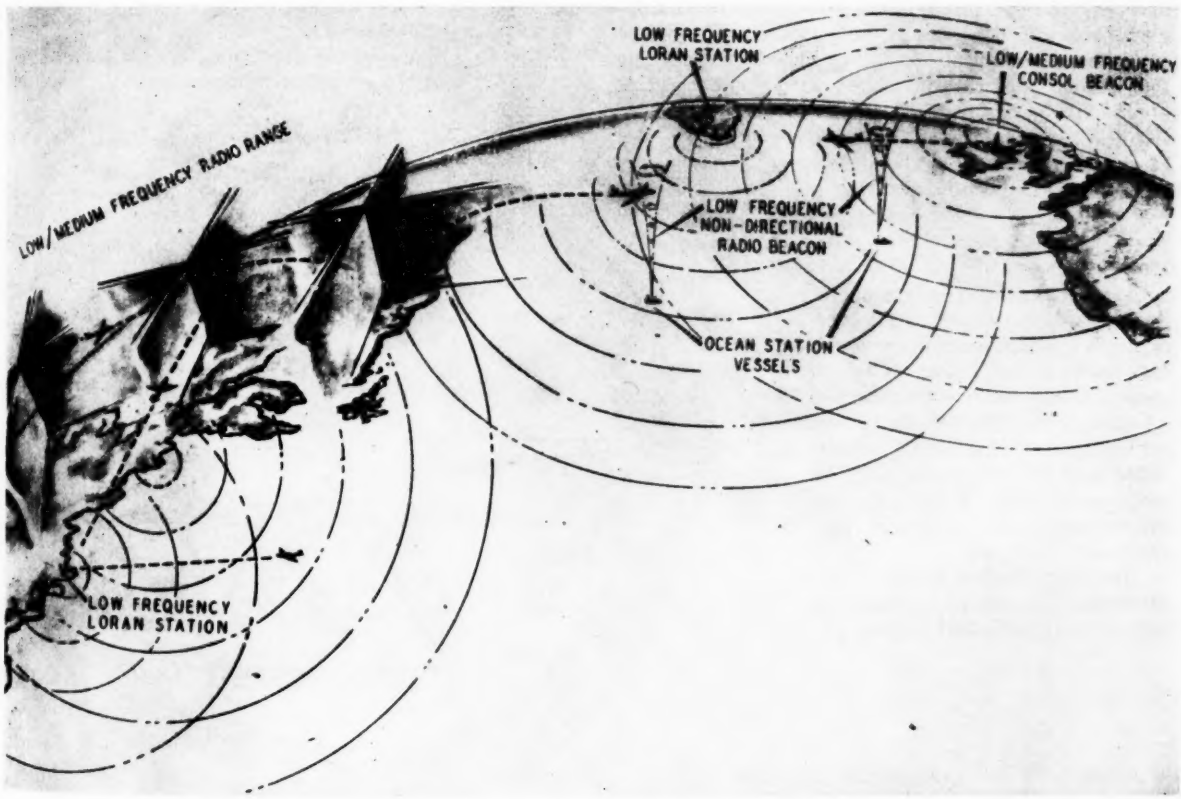

LOW FREQUENCY LORAN STATION
LOW/MEDIUM FREQUENCY CONSOL BEACON
LOW/MEDIUM FREQUENCY RADIO RANGE
LOW FREQUENCY NON-DIRECTIONAL RADIO BEACON
OCEAN STATION VESSELS
LOW FREQUENCY LORAN STATION

FIGURE 3. Navigational aids.

the assistance he needs during the last four miles of the approach to a landing. The latest type of I.L.S. is needed to eliminate the deficiencies of the earlier installations. The problem here is again one of implementation. The aeroplanes should be equipped with automatic approach equipment by tying in the I.L.S. with the autopilot.

Even with the above there is a very definite need to have a continuous distance indication throughout the approach. Although greater accuracy is needed during the final approach than now achieved with D.M.E., the same equipment could probably be developed for common use as a short and medium range navigational aid and as an aid during final approach.

Precision G.C.A. (Ground Controlled Approach Radar) is actually unnecessary at airports equipped with I.L.S. but if installed it could be helpful on occasion. G.C.A. itself needs little improvement but its operators need considerably more practice in its operation than they now get at some places. It must be remembered that G.C.A. is basically for monitoring purposes. The pilot will normally make his approach on I.L.S. and, with the improvements now being planned for this facility, it should be more suitable for both current and the future jet aeroplanes.

LANDING CONTROL

The new A.C.L.S. (Automatic Carrier Landing System) being developed by Bell Aircraft for the U.S. Navy shows great promise with over 1,200 blind landings made with it up to the present time. This device would be most welcome as a supplement to complete the landing automatically after an automatic I.L.S. approach. It has been stated that A.C.L.S. can land any aeroplane equipped to use I.L.S.; and commercial production could be available in two years.

MESSAGE HANDLING

Planning for jet aeroplane operations has revealed few really new needs in telecommunications, but it has revealed the extent to which current operations are handicapped by existing facilities. While we are getting by with what we have today, safety and economy will both be jeopardised in the turbine era unless improvements are made in telecommunication aids.

The big problem is how to handle all the messages needed in connection with air transport; and particularly, how to handle them with the speed necessary to be of any assistance to jet aircraft. I.A.T.A. recommends:—"Jet operations highlight the need for a reduction in communication work load on aircraft crew and also a reduction in the loading of communications channels. To this end the volume of communications should be reduced by procedural means and the speed of transferring intelligence increased by improved reliability of existing techniques and the development of new communications methods."

ROUTINE REPORTING—AIR TO GROUND

Although new automatic devices such as radio-teletype, facsimile transmission, and so on, will undoubtedly assist in improving the situation, it appears that the greatest improvement will be achieved in time for 1960 by concentrating on improving existing communications facilities.

The routine reporting of an aeroplane in many areas is associated with its geographic location. By doubling the speed of the aeroplane it either halves the time between position reports, or the aeroplane must omit reporting over locations so close together. This, as can be imagined, can lead to political prestige problems in areas like Europe, because every country wants to control aeroplanes over its territory. The problem of co-ordination between ground-to-ground and air-to-ground services is tremendous and a solution has not yet been found.

The Aeroplane

The airlines believe, and hope, that the least of our worries concerned with jet transport operations will be

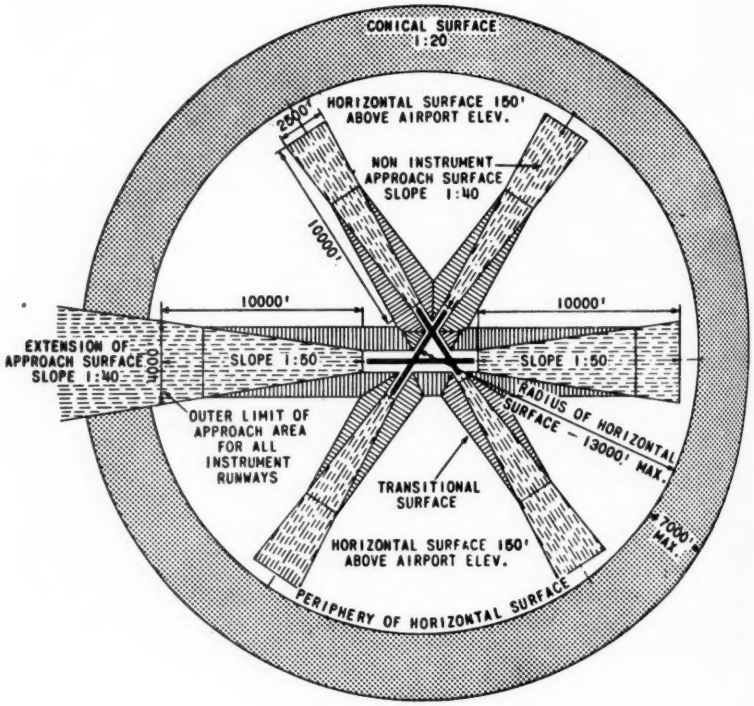


FIGURE 4. I.C.A.O. airport zoning.

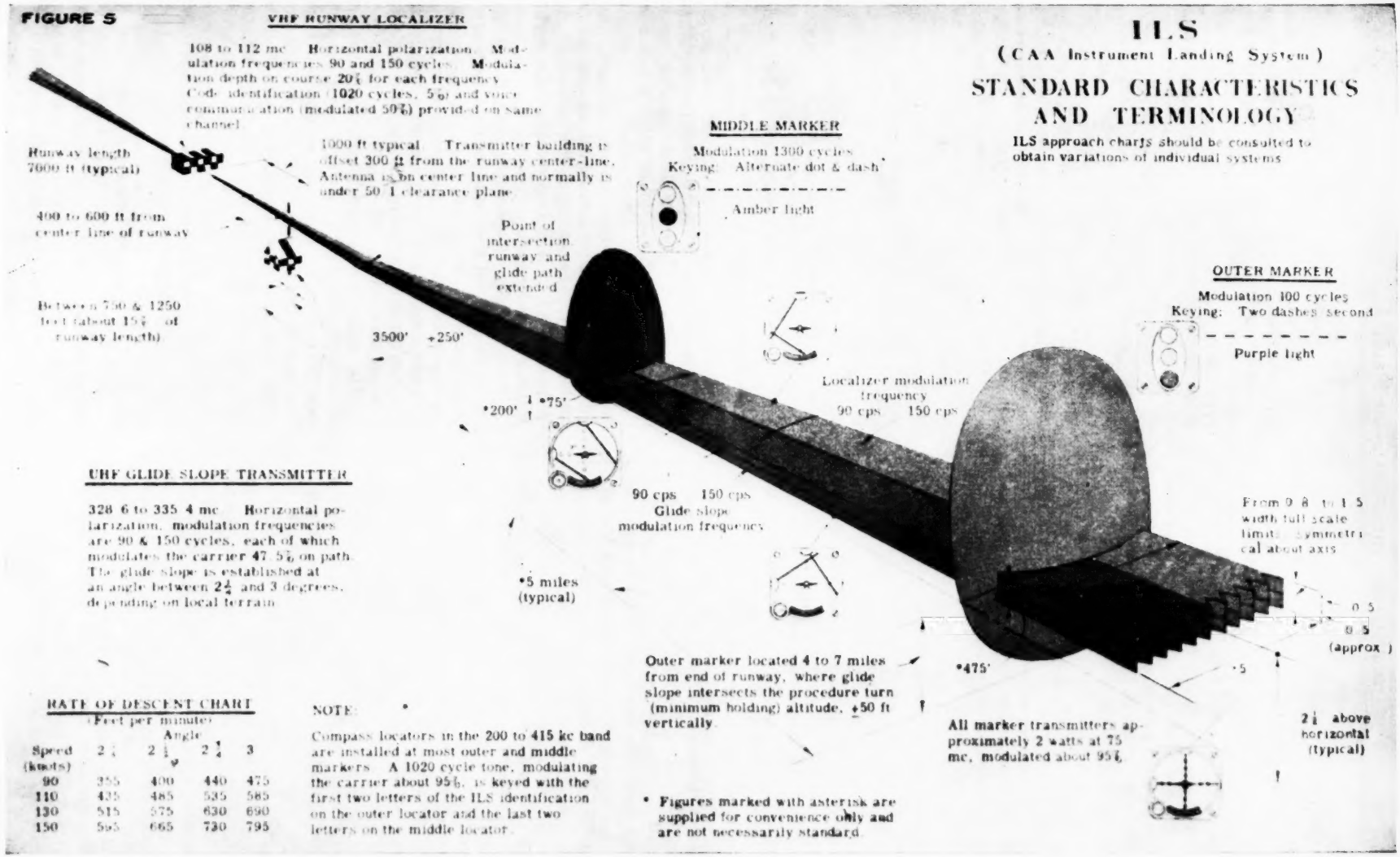


FIGURE 5
VHF RUNWAY LOCALIZER
108 to 112 mc Horizontal polarization. Modulation frequencies 90 and 150 cycles. Modulation depth on course 20% for each frequency. Code identification 1020 cycles, 5%; and voice communication (modulated 50%) provided on same channel.
1000 ft typical. Transmitter building is offset 300 ft from the runway center-line. Antenna is on center line and normally is under 50 ft clearance plane.
Runway length 7600 ft (typical)
400 to 600 ft from center line of runway
Between 750 & 1250 feet (about 15% of runway length)
Point of intersection runway and glide path extended
3500' ±250'
•200'
•75'
•5 miles (typical)
MIDDLE MARKER
Modulation 1300 cycles
Keying: Alternate dot & dash
Amber light
OUTER MARKER
Modulation 400 cycles
Keying: Two dashes/second
Purple light
Localizer modulation frequency
90 cps 150 cps
90 cps 150 cps
Glide slope modulation frequency
UHF GLIDE SLOPE TRANSMITTER
328.6 to 335.4 mc Horizontal polarization, modulation frequencies are 90 & 150 cycles, each of which modulates the carrier 47.5% on path. The glide slope is established at an angle between 2½ and 3 degrees, depending on local terrain.
Outer marker located 4 to 7 miles from end of runway, where glide slope intersects the procedure turn (minimum holding) altitude, ±50 ft vertically.
•475'
•5
All marker transmitters approximately 2 watts at 75 mc, modulated about 95%
From 9.8 to 1.5 width full scale limits symmetrical about axis
0.5
0.5
(approx.)
2½ above horizontal (typical)
ILS
(CAA Instrument Landing System)
STANDARD CHARACTERISTICS AND TERMINOLOGY
ILS approach charts should be consulted to obtain variations of individual systems
RATE OF DESCENT CHART
(Feet per minute)
Angle
Speed (knots) 2 | 2 ¼ | 2 ½ | 2 ¾ | 3
90 355 400 440 475
110 435 485 535 585
130 515 575 630 690
150 595 665 730 795
NOTE:
Compass locators in the 200 to 415 kc band are installed at most outer and middle markers. A 1020 cycle tone, modulating the carrier about 95%, is keyed with the first two letters of the ILS identification on the outer locator and the last two letters on the middle locator.
• Figures marked with asterisk are supplied for convenience only and are not necessarily standard.

FIGURE 5. I.L.S. (C.A.A. instrument landing system). Standard characteristics and terminology. I.L.S. approach charts should be consulted to obtain variations of individual systems.

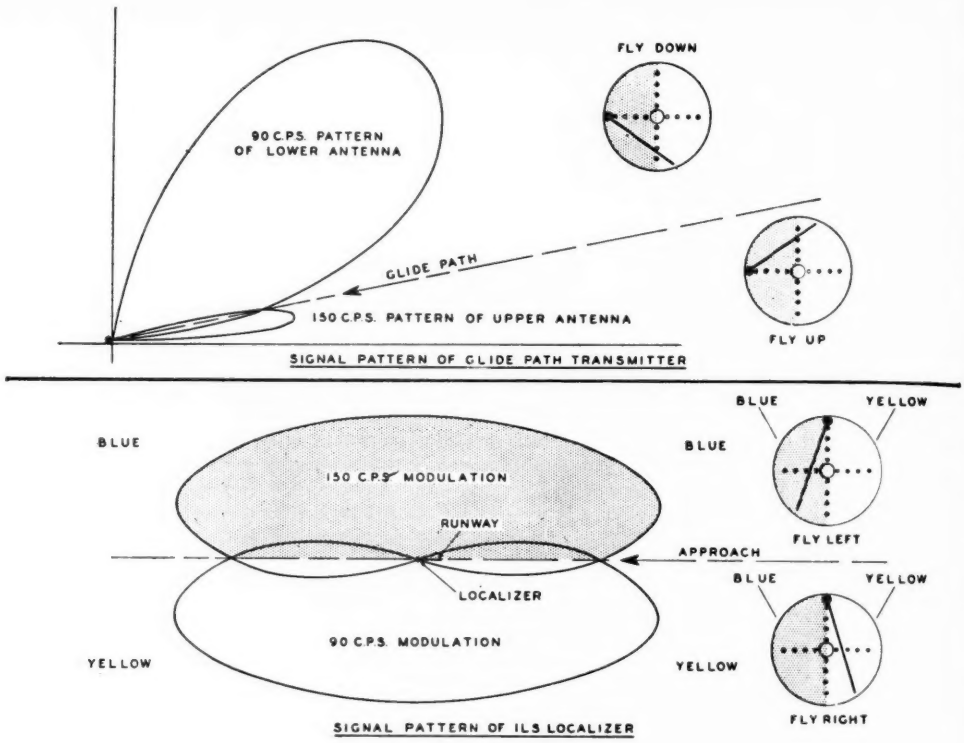


FIGURE 6. Signal patterns of glide path transmitter (*above*) and of I.L.S. localiser (*below*).

the aeroplanes themselves. This is partly due to the pioneering efforts of de Havilland and B.O.A.C., but chiefly to the tremendous amount of research and development going into the design of the new big jet transports. There are however, a few points that are worrying some of the airlines.

COCKPIT

An important feature of the jet aeroplane is that the simplicity of its engine operation permits the cockpit to be designed from scratch on the basis that the aeroplane can be operated solely by one man. A second crew member would, of course, be available as a standby, or to assume certain duties in normal conditions.

The problem is to get some of the airlines, the manufacturers and government authorities of the United States into this frame of mind. They have been imbued for so long with the concept that any aeroplane weighing over 80,000 lb. needs a third crew member, that they no longer analyse the situation impartially.

Those who have made studies, and this includes some U.S. manufacturers, agree that a jet aeroplane can be designed to relieve the work load on the crew to such an extent that the aeroplane can be safely operated with a two-man crew. Whether or not a particular aeroplane requires a two- or three-man crew will, of course, depend upon the manner in which the designer has treated the design of the cockpit in that aeroplane.

We feel that one cannot over-stress the importance of achieving simplicity in a cockpit design, and the importance of reducing the dependency upon the human element to a minimum. The large jet aeroplanes make this objective both desirable and achievable, with some effort on the part of all concerned. As Bill Stout used to say: "Simplicate and add more lightness."

WEIGHT AND C.G. CONTROL

Aeroplane fuselages have become so long that a real problem prevails even today in distributing the baggage and cargo load so as to keep the c.g. of the aeroplane within permissible limits.

Passenger Service personnel and the travelling public itself do not wish to have any restrictions as to where the passengers may sit.

Station Service personnel would like to be able to segregate baggage and cargo according to its destination, to expedite unloading and to hold station-stop times to a minimum.

The airline must establish loading procedures and controls to ensure that by the most adverse accumulation of permissible tolerances of the load in each loading zone, the final c.g. of the aeroplane will remain within permissible limits. The complexity of achieving this quickly, particularly where there are last minute changes to the load, is a real problem. The development of a low cost electronic computer—an electric Librascope type of device—is needed. Normally, quick methods involve restrictions to loading.

TAKE-OFF "GO—NO GO" INDICATOR

With current aeroplanes, the pilot can almost always recognise if anything is wrong with the normal take-off acceleration of the aeroplane in time to cut power and stop on the runway. Because a jet aeroplane is cover-

ing ground so quickly during the latter part of its take-off run too much of the runway may be covered before the pilot recognises that all is not well. It would, therefore, be most helpful if some indicator could be made available to let the pilot know throughout the take-off run whether or not the acceleration of the aeroplane is as it should be. Such a device has been tested experimentally but is not available, so provides a problem worthy of solution.

FUEL CONTROL UNIT

The characteristics of a turbine engine are such that it can burn as fuel almost anything from perfume to cough-syrup, provided the fuel control unit is adjusted for the specific gravity of the fluid. It appears that the airlines of the world have now decided to use either kerosine or JP-4 (wide cut gasoline). Because kerosine is the cheaper in some areas, and JP-4 in others, it would be helpful if the operator could use either, even to the point of adding one to a part tankful of the other, with the fuel control system adjusting itself automatically to the prevailing specific gravity.

The Rolls-Royce Conway fuel control can do just this, as it compensates automatically to the specific gravity of the fuel over a range wide enough to encompass both types of fuel. The problem is to accomplish as much with all civil turbine engines.

FIRE PREVENTION

Because a turbo-jet engine does not have a propeller to strike the ground in a crash and stop the engine, the rotating parts might continue to spin in some accidents. This means that fuel vapours from burst tanks could be drawn into the engine by the rotating compressor and ignited by the hot turbine wheel.

It has also been demonstrated that, regardless of the fuel used, JP-4 or kerosine, a quick fire can occur if a high speed impact results in fuel being splashed, or sprayed, as small particles which come in contact with a hot part of the engine.

The N.A.C.A. has developed a means of preventing such fires by automatically and instantaneously spraying all hot parts of the engine with water when a crash occurs. The N.A.C.A. fire prevention system has great potentialities, but there are still many problems to be solved to achieve its implementation. It is sincerely hoped that both the engine and aeroplane manufacturers will continue to study how best to reproduce in a practical light-weight manner, what the N.A.C.A. has accomplished with an installation that is a bit too heavy for normal service. The question also remains—will an accidental discharge of the water on the hot parts damage them?

FUSELAGE DAMAGE

It has been next to impossible to prevent damage to the fuselage of existing aeroplanes, chiefly around doors, as a result of mishandling of loading and servicing equipment. Because of the high fuselage pressure differential that will be encountered with jet aeroplanes, it is most important that such damage does not occur. It will be quite a problem to keep Station Service personnel continually aware of the importance of preventing damage to the fuselage, even though the future servicing equipment is well padded.

HUMIDIFICATION

B.O.A.C., the only airline with actual civil jet experience, have said that, in their opinion, humidification to at least 20 per cent relative humidity is essential in jet transports for the comfort of both passengers and crew. The U.S. manufacturers are studying the problem of how to achieve adequate comfort with an acceptable weight penalty.

NOISE SUPPRESSORS

The noise of jet engines creates a problem. Jet engines as used today are objectionable, but they should not be considered as a criterion of the future. The entire Industry is aware of the situation and the engine and airframe manufacturers and research laboratories are all sparing neither time, nor money, in their efforts to have an adequate solution before the civil jets go into service.

Exhaust noise suppressors capable of achieving a 10 decibel noise reduction have been designed and are expected to weigh around 300 lb. per engine. Even more efficient noise suppressors (18 decibel reduction) have been tested, but so far have had too much adverse effect on performance. The Industry is still hoping for a good practical design somewhere between the two. Suffice to say that the Industry is now confident that there will be no more noise from jets, insofar as neighbouring residents are concerned, than there is today from reciprocating-engined aeroplanes—and in case this is considered to be a tongue in cheek remark, we can add that because of the high angle of climb possible with the jets the public will be less disturbed by jet noise than they are with today's aeroplanes.

There is another noise problem which is only important on the ramp; this is the piercing compressor whine (2,000 c.p.s. during taxying and idling) directly in front of the aeroplane when it is manoeuvring on the ramp.

THRUST REVERSERS

Because a jet aeroplane does not have a propeller that can produce reverse thrust to stop the aeroplane during its landing roll, some other means of arresting the jet aeroplane is required. Otherwise, a continual heavy application of wheel brakes would be necessary. The manufacturers have evolved designs that permit the pilot to obtain, in a reverse direction, 50 per cent of his normal forward thrust with no loss of engine thrust when the device is not in use. The reverser is expected to weigh around 250 lb. per engine. The manufacturers are a bit handicapped in designing both the noise suppressor and thrust reverser because their installations must be compatible with each other. There is ample scope for ingenious designers in this field.

Engines

The interconnection time of propeller turbines must be shortened, with the ability to adjust without shutting

down the engine or opening large cowl panels. The interconnection, as well as being simplified, must be capable of handling large subsequent changes in ambient temperature without having to re-interconnect. Automatic control for limiting critical variables such as J.P.T. is required, definitely to prevent an over-speed, even with any two mechanical failures. Automatic de-icing actuation is desirable with a warning light in the cockpit to indicate when the de-icing is " ON."

An automatic device is desired for recording compressor speeds, flame temperature, outside air temperature, ram pressure ratio and fuel flow, in order to tell Maintenance how the engine has been operating. The maintenance and operational limits for the engine must be practical, that is, within $\pm 10°$ tolerance for J.P.T. gauges, and so on. At the present time engine manufacturers are prone to establish limits which are impractical to follow because of gauge errors, and so on. The sensing equipment itself used on the engine must be as reliable and as rugged as the working components being checked.

Turbine engines should be designed for the independent overhaul of major components so that the turbine wheel, the compressor, the combustion chambers, and the reduction gearing where applicable, may each be overhauled at different time intervals. Hence, the major sections of a turbine engine should be quickly replaceable. The test bed time should be considerably shortened. Accessories should be checked on their own test rig in order to avoid delays in engine check-out due to accessory malfunctioning.

Miscellaneous Problems

There are many problems that do not come under any of the previous headings. A few typical ones are:

AUTOMATIC RESERVATIONS SYSTEM

The problem of making reservations easily, accurately, and quickly, has already become so acute that some means must be found to alleviate the situation before the jet era arrives. T.C.A. has been active for the past few years in the development of an electronic data processing scheme which will not only handle the reservations system, but also accounting, stores inventory, aircraft position reports, and so on. Several airlines in the United States have started, or are about to start, using automatic reservations systems. Such systems can confirm a reservation in a matter of seconds or inform the requester of the first available opening.

T.C.A. expects to have a " pilot " system working in one area this year and if it is successful, concentrated efforts will be made to have the system in general use by the time the jet transports go into service.

FLIGHT SIMULATOR

Because it will cost upwards of $1,000 an hour to fly the big jet transports on local training, it would be helpful to do the maximum practicable amount of flight crew training on the ground. A full flight simulator would permit the vast majority of training to be accomplished without flying the real aeroplane but such a device can cost well over a million dollars. Many airlines believe that from an economic standpoint a " semi-simulator " or " type trainer " would be adequate and preferable to a full simulator. An extensive analysis is required by each airline into its own problems to establish the degree of simulation that is desired for the training of both its flight and ground personnel.

INTRODUCTION OF NEW TYPE AIRCRAFT INTO FLEET

We have reviewed many of the problems facing the Industry in general associated with the use of turbo-jet transports. There is another group of problems that face each airline when it introduces a new type of aeroplane into its fleet. We have not attempted to discuss any of these problems in this paper because they are not unique to the new jet transports. In this case it is merely more important that they be solved correctly, because of the larger amount of money invested in each of the new aeroplanes. Sufficient work is involved that the airlines will be severely pressed during the next two years to plan adequately maintenance and overhaul facilities, passenger and station services equipment, and the training of personnel in all departments. This could itself be the subject of a paper.

Conclusions

It will be evident from the foregoing outline of typical problems that much work will be done during the next two years in order to solve them and so get the most benefit from the next generation of air transports.

The airlines, manufacturers, and organisations such as I.C.A.O. and I.A.T.A. are continually studying operational requirements and bringing recommended actioning to the attention of those concerned, with the object of keeping the entire Industry advancing together as a co-ordinated body.

The outlook for achieving this is bright to those in the Industry, because they know what they have accomplished when under pressure in the past, and the current problems are no worse than previous ones.

Fifteen or twenty years from now someone will be presenting a paper to the Royal Aeronautical Society, outlining a similar number of problems associated with the coming " vertical take-off supersonic jet transports." They will look back on the " flying-bedstead " of today as the pioneer of their new era, just as we look back on the simple Whittle and Heinkel engines and the Comet and Jetliner transports as forerunners of our coming jet era. Some might even reminisce about the pre-turbine age when many airlines followed the quaint custom of buying new aeroplanes with their own money.

Electronic Control Techniques in Aircraft Manufacture

by

G. S. KERMACK, A.F.R.Ae.S., and H. OGDEN, A.F.R.Ae.S.

(Ferranti Ltd.)

PART 1

1. Introduction

This paper is concerned with a method of improving the utilisation of metal cutting machine tools and thus deals with that part of production covered by machining. It is particularly applicable to the Aircraft Industry, where the production of military aeroplanes must be as rapid as possible and the costs of civil aircraft in a competitive market must be kept to the minimum. As it is designed to be used in conjunction with small quantity manufacture it can be of great assistance in development work.

The limitation to the rate at which machining of any part can take place is generally dictated by the rate at which information can be transferred to a machine tool and converted into appropriate slide movements. In large scale manufacture where batch sizes are high, this transfer of information is normally effected by elaborate pre-set tooling arrangements and the cost and time required to prepare this information is acceptable only as the cost per part becomes very small. In aircraft manufacture, however, the critical stage is when a prototype is required, or when a modification has to be introduced and, moreover, even production batch sizes are often small. The preparation of complex tooling arrangements is normally excluded on economic grounds and, as a result, a very large proportion of the machining of aircraft parts is done by hand. This implies that the rate of machining and metal removal is very low because a human operator is fundamentally incapable of thinking in more than one dimension at a time, and has to undergo an elaborate process for the mental conversion of information from a drawing into individual hand movements.

Over a long period, ways have been sought for overcoming this difficulty and, until recently, they have almost invariably taken the form of copying processes using templates or models. These templates themselves, of course, involve the use of skilled labour in their own preparation and, for small batch quantities, only small improvements in overall time can be obtained by their use.

The rapid development of electronic control methods in almost every field has pointed the way to the achievement of a considerable increase in the rate of transfer of information in the machining field, and this is of interest to the Aircraft Industry for the following reasons: —

1. Electronics are flexible. This is highly significant when the manufacture of parts in quantities ranging from single units to several dozens is required, and means that a single machine can be called upon to manufacture completely different shapes without any alteration to the machine itself and without individual jigs or fixtures.
2. Electronics are very fast in operation. While this is important in any manufacturing process it is particularly true in the case of aircraft and their power plants, where development is proceeding at a higher rate than in any other industry, and where change and the necessity for rapidly introducing changes is paramount. Moreover, under electronic control very much greater feedrates, which are highly desirable, can be achieved than can be obtained with operator control.
3. The shape of every aircraft part is critical for aerodynamic or structural reasons. This is perhaps the most important single factor when considering control methods for manufacture as it implies that the shapes of parts are always available in numerical terms as they have been derived from a process of mathematical analysis.

The addition of high performance servo-mechanisms to a machine tool operating from magnetic tape can therefore increase the amount of work available from a tool by five, ten, or even fifty times, compared with its manually-operated equivalent. Additionally, a machine such as a vertical mill can be made much more versatile as, frequently, a complete machining operation on a complex part can be done in one set up, when conventional methods require several separate operations, sometimes on different machines.

It is, however, extremely important to arrange that the preparation of the information for supply to the machine tool itself should be rapid and cheap when small batch sizes are considered, otherwise the advantages obtained by the use of high feedrates will be lost in the additional time and cost of the stages proceeding machining. Modern digital computing methods enable the control information to be obtained from the minimum initial data quickly and at low cost, and no

A Section Lecture given on 17th January 1957.

FIGURE 1.

specialised skills are required. Since one of the aims of a control method must be to make better use of available skills, this last point is of importance.

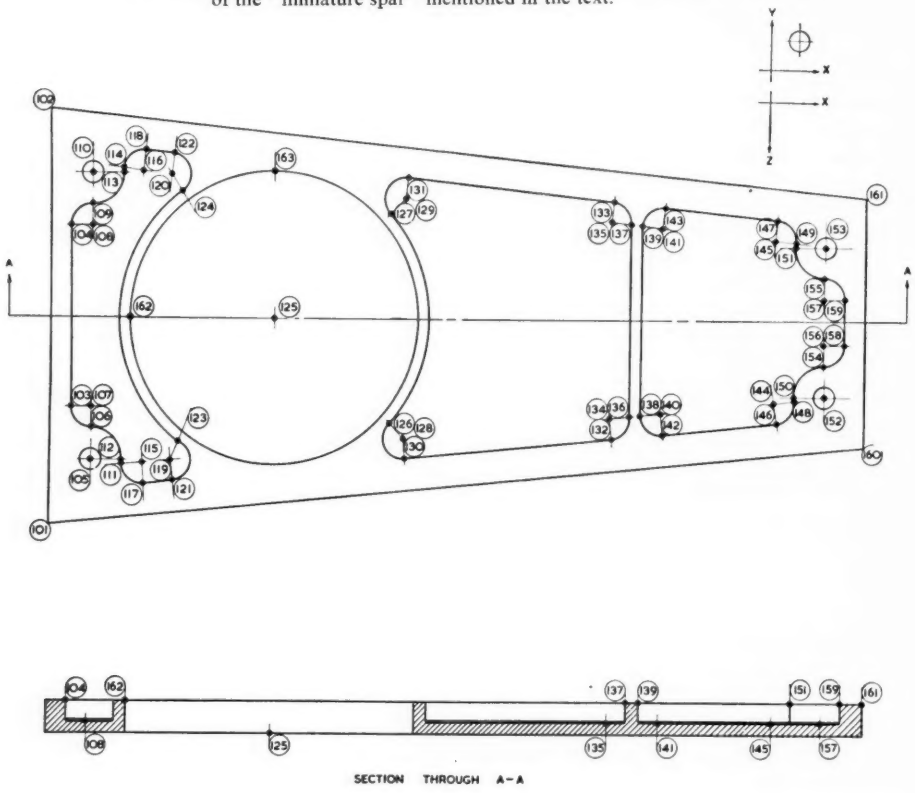
2. Description of System

The system for achieving the foregoing aims has been described in full elsewhere[1], but for the sake of completeness is outlined below. A photograph of the control cabinet associated with the tool is shown in Fig. 1. Some of the equipment is described in detail in the second part of this paper.

The stages are as follows: —

1. The drawing of the part is prepared using a system of co-ordinate geometry for dimensioning, the positions of the necessary points on the parts being specified by reference to a system of arbitrary rectangular axes. The significant points are defined as " change points," that is to say the points where one type of curve intersects another. For example, two points are required to specify a straight line—the position of the beginning and the end of the line, and three points are necessary to describe an arc—the position of the beginning and the end of the arc together with the position of the centre of the circle of which it is part. Note that this is the minimum number of points which are

FIGURE 2. A typical drawing dimensioned with reference to a system of rectangular axes. The points of intersection of each curve—the " change points " are specified. This drawing is of the " miniature spar " mentioned in the text.



CHANGE POINTS	X CO-ORD	Y CO-ORD	Z CO-ORD
101	1.7500	1.000	7500
102	1.7500	6.000	7500
103	2.000	2.4062	3750
104	2.000	4.5938	3750
105	2.2500	1.7812	3750
106	2.2500	2.1562	3750
107	2.2500	2.4062	6250
108	2.2500	4.5938	6250
109	2.2500	4.8438	3750
110	2.2500	5.2188	3750
111	2.6250	1.7406	3750
112	2.6250	1.7812	3750
113	2.6250	5.2188	3750
114	2.6250	5.2594	3750
115	2.8750	1.7406	6250
116	2.8750	5.2594	6250
117	2.8999	1.4918	3750
118	2.8999	5.0106	3750
119	3.2542	1.7786	6250
120	3.2542	5.2214	6250
121	3.2791	1.5298	3750
122	3.2791	5.4702	3750
123	3.4008	1.9811	3750
124	3.4088	5.0189	3750
125	4.5000	3.5000	7500
126	5.8782	2.2289	3750
127	5.8782	4.7711	3750
128	6.0620	2.0594	6250
129	6.0620	4.9406	6250
130	6.0869	1.8106	3750
131	6.0869	5.1894	3750
132	8.6499	2.0668	3750
133	8.6499	4.9332	3750
134	8.6250	2.3156	6250
135	8.6250	4.6844	6250
136	8.8750	2.3156	3750
137	8.8750	4.6844	3750
138	9.000	2.3782	3750
139	9.000	4.6218	3750
140	9.2500	2.3782	6250
141	9.2500	4.6218	6250
142	9.2749	2.1294	3750
143	9.2749	4.8706	3750
144	10.6250	2.5156	6250
145	10.6250	4.4844	6250
146	10.6499	2.2668	3750
147	10.6499	4.7332	3750
148	10.8750	2.5156	3750
149	10.8750	4.4844	3750
150	10.8750	2.5938	3750
151	10.8750	4.4062	3750
152	11.2500	2.5938	3750
153	11.2500	4.4062	3750
154	11.2500	2.9688	3750
155	11.2500	4.0312	3750
156	11.2500	3.2188	6250
157	11.2500	3.7812	6250
158	11.5000	3.2188	3750
159	11.5000	3.7812	3750
160	11.7500	2.0000	7500
161	11.7500	5.0000	7500
162	2.7500	3.5000	3750
163	4.5000	5.2500	3750

required to define the shape of any part, however dimensioning is done. A typical "ordinated" drawing is shown in Fig. 2.

2. A planning sheet is prepared using the drawing. This is basically a non-mathematical operation, performed by a man with machining knowledge. This "programming engineer" first decides the basic machining information, *i.e.* the cutter feedrate and the cutter diameter and then the sequence in which the cutting operations are to take place. The basic machining data is entered on the planning sheet and can be changed at any time during the subsequent programme. The planning sheet is then completed by filling in blank columns with co-ordinates of the change points of the workpiece in the order in which they will be encountered in the machining operation, together with a simple statement defining the type of curve involved, *e.g.* CIR for circle, ELL for ellipse, INT for interpolation, and so on. The completed sheet is then copy typed on a teleprinter machine which produces an equivalent strip of punched paper tape. The time required to prepare and type a planning sheet is independent of the size of the part as it is unaffected by scale. A planning sheet is shown in Fig. 3.

   It should be noted that this type of planning operation is the simplest conceivable system as it requires only the minimum information to specify the shape of the part. It represents the ultimate in ease of programming for any existing or projected system of numerical control.

3. The paper tape programme is fed to a special digital computer whose function is to calculate the continuous path of the tool in terms of the measuring systems fitted to each of the two or three axes of the machine. In doing so it takes into account the diameter of the cutter, the feedrate required and the type of curve specified between the change points given. For example, a semi-circular arc 50 in. long (for which three points have been given) is expressed by the computer in terms of more than 63,000 separate signals when the digit size on the tool is 0·001 in. The output of the computer is recorded on a multi-channel magnetic tape, with a channel for each axis of the tool, plus an additional channel for checking purposes. The special computer operates at eight times the machining speed, so one computer is capable of providing tapes for a large number of machine tools even with a low duplication factor. There will be no necessity for the user of a controlled tool to own a computer, as computer time can be purchased from a control service.

4. The magnetic tape is fed to a control unit associated with the machine tool. When played back, the servo-mechanisms on each slide carry out the demanded movements and machining proceeds unattended, apart from general supervision and any cutter changes that may be called for. The demanded feedrate is precisely achieved throughout the operation.

3. Costs

A general account of the economics of electronically-controlled machining is given below to enable an assessment of the costs to be obtained and compared with the costs of manual operations for the same part.

A—COSTS WHICH ARE INDEPENDENT OF BATCH SIZE

(*i*) *Programming costs*:
These are defined as the time of a programming engineer with a part-time copy typist. A year of 2,000 working hours is assumed. It should be noted that more than one programming engineer per tool may be needed if batch sizes are very small, but this does not affect the following calculations.

TABLE I

Programming Engineer	
Salary £800 per annum plus employer's services £200 per annum ...	=£1,000 per annum
Typist	
Half time at £450 per annum including employer's services	= £225 per annum
	Total=£1,225 per annum or 13s. per hour

(*ii*) *Computing costs*:
These are made up of the charge for computer service (£15 per computer hour) and a proportion of the cost of the magnetic tape. The tape when used to complete the machining of a particular batch will normally have the recording removed, so that a further different recording can be made on it. The cost of tape per hour is therefore incurred in wastage as the result of accidental damage, plus a factor which will be dependent on the extent to which recorded tapes are retained (normally it will be more convenient to store the paper tape programme). In the following it is assumed that the average will be represented by a figure of £1 per hour of machining time on the first of any particular batch.

TABLE II

Computer cost per machining hour	1 17 8
Magnetic tape per machining hour	1 0 0
Total=	£2 17 8
	or, say 58s.

B—COSTS WHICH ARE REPEATED FOR EACH OF A BATCH

(*i*) *Machining costs* (*machine tool only*)
A capital cost for the machine of £2,000 is assumed. This represents a small vertical mill and the figure is used as the parts described below were made on a machine of this type.

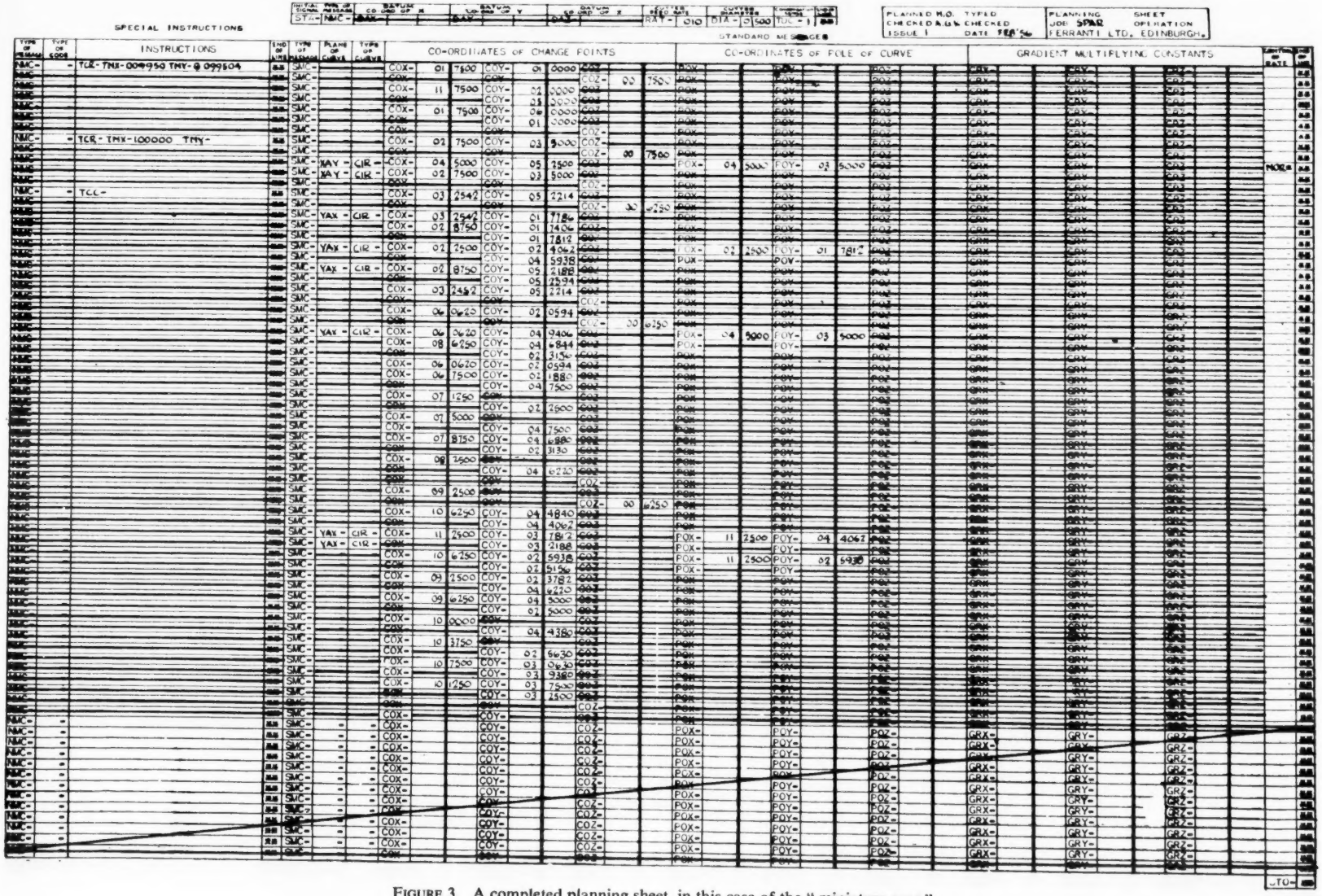


FIGURE 3. A completed planning sheet, in this case of the " miniature spar."

In most aircraft work a large and more expensive machine would be involved, but the calculation would, of course, be similar and the cost is common to both electronically-controlled and manually-controlled machining. The capital is written off over ten years. A 75 per cent utilisation is also assumed over a year of 2,200 working hours. This is high for a manually-controlled tool on work of this nature, but easily achievable on a numerically-controlled machine.

The cost of the operator will vary in different districts and may tend to be somewhat higher in certain localities.

(*ii*) *Control system costs*:

A capital cost of £15,600 is assumed for a three-dimensional system made up of:

	£
Control equipment	13,000
Power supplies	1,000
Teleprinter	600
Conversion of tool	1,000
	£15,600

If more than one controlled tool is in use the average capital cost will be slightly less, as the cost of the teleprinter and power supplies will be shared.

As before, a 75 per cent utilisation is assumed, and capital is written off in ten years.

4. Estimation of Machine Utilisation and Costs for a Particular Batch

With the foregoing information it is possible to arrive at a reasonably accurate assessment of the cost of machining any part and this can be compared with collected costs for conventional machining. The cost for conventional machining must, of course, include the cost of templates or any special pieces of "information" which have been prepared before actual machining takes place.

TABLE III

Annual Costs	*Single shift* 1650 hours	*Double shift* 3300 hours	*Treble shift* 4950 hours
	£	£	£
Average interest on Capital (6 per cent on written down value)	63	63	63
Depreciation	200	200	200
Floor area costs (80 sq. ft.)	20	20	20
Insurance	4	4	4
Production auxiliaries (power, etc.)	17	34	51
Maintenance	16	24	32
Consumable Tools	78	156	234
	£398	£501	£604
Cost per hour, say	5s.	3s.	2s. 6d.
To this should be added the cost of the operator and his services 10s. per hour making the totals	15s.	13s.	12s. 6d.

In the following it is assumed that an "ordinate" drawing is available. The cost of preparation of an ordinated drawing can be taken as 10 per cent greater than the cost of a conventional drawing.

Raw material costs are not included as they will be common to each method.

The procedure is as follows:

1. Machining Time: This is estimated by measuring the distance to be travelled by the cutter for each feedrate, and dividing by the appropriate feedrate. A "map measure" is useful for this purpose, and feedrates can be obtained from standard charts.
   Let machining time be called M (hours).
2. Programming Time: This is assessed by obtaining the number of "change points" on the drawing. This will be roughly equal to the number of "lines" on the planning sheet, and a time of two minutes per "line" can be allowed for total programming time (including checking). This figure may vary between one and three minutes per line, but is true for the example given below.
   Let programming time be called P (hours).
3. Computing Time: As has already been explained, the computer operates at eight times the machining speed for the first part. In the foregoing, however, computing costs have been derived in relation to the time in hours of machining. The computing time is, therefore, for the purposes of this calculation, equal to the machining time on one part.
4. Machining Costs: These are the sum of the costs for both control system and tool (Tables III and IV). They may be reduced if more than one machine is in use, as 100 per cent supervision is not necessary, and the costs of supervision can be spread. In the following, however, 100 per cent supervision is assumed. For a batch size of N, therefore, the basic cost in shillings of manufacture per part by the electronically-controlled method can be expressed as:

$$S = \frac{13P}{N} + \frac{58M}{N} + 15M + 38M$$

i.e. $$S = \frac{13P}{N} + \frac{58M}{N} + 53M$$

TABLE IV

	Single shift 1650 hours	*Double shift* 3300 hours	*Treble shift* 4950 hours
	£	£	£
Average interest on capital (6 per cent of written down value)	468	468	468
Depreciation	1560	1560	1560
Maintenance and Spares	1000	1500	2000
Floor area (80 sq. ft.)	20	20	20
Insurance	40	40	40
Production auxiliaries	40	80	120
	£3128	£3668	£4208
Cost per hour	38s.	23s. 3d.	17s.

This is for single shift working, the third factor being reduced appropriately for double or treble shift working. An allowance for loading requires to be added to this figure.

It will have been noticed that no figure for fixtures has been included, in view of the impossibility of generalising on this point. It can be said, however, that the cost of fixtures for conventional machining will normally be greater than for computer-controlled milling, where the requirement is normally simply that of holding the workpiece in one position.

5. Examples

(A) MINIATURE SPAR (Fig. 4)

Accuracy requirements all dimensions ±0·001 in. Batch size 5.

1. Machining Time: Distance travelled by cutter —140 in.
   Feedrate 10 in./minute.
   Machining time therefore $\frac{14}{60} = M$.
2. Programming Time: Number of change points 63.
   Therefore time for programming 2×63 mins. say 2 hours $= P$.

Substituting in the above formula for a batch size of 5, a basic cost of 20/4 per part is obtained. Allowing five minutes per part for loading the machine the cost becomes 25/-.

An estimated cost per part for conventional working (5·6 hours average) is 83/-.

The cost of computer-controlled machining is therefore 30 per cent of the cost by conventional means.

Actual total times on the tool are 95 minutes for computer-controlled milling as opposed to 28·2 hours for conventional methods. Utilisation of the tool is therefore increased by a factor of 18.

(B) MILLED BLOCK (Fig. 5)

Accuracy requirements all dimensions ±0·001 in. Batch size 1.

1. Machining Time:
   Obtained from:

130 in. at	7 in. per min.	= 18·5 mins.
69 in. at	10 in. per min.	= 6·9 mins.
24 in. at	3 in. per min.	= 8·0 mins.
	Total	= 33·4 mins.

   In this instance both a roughing and finishing cut is required. The same tape is used (but different cutter diameters). M in the third factor is therefore $\frac{33{\cdot}4 \times 2}{60}$ hours, but in the second factor $\frac{33{\cdot}4}{60}$ hours.
2. Programming time:
   Number of change points = 135.
   Therefore time of programming $\frac{2 \times 135}{60} = 4{\cdot}5$ hours.

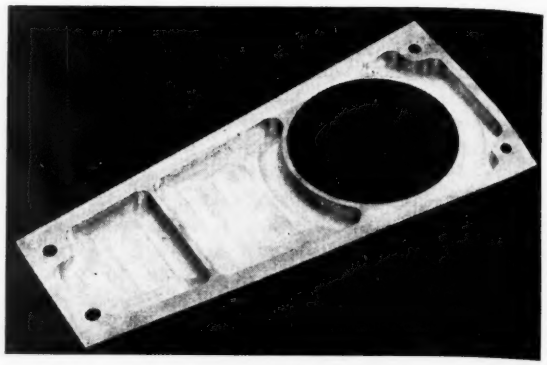


FIGURE 4. Miniature spar.

The basic cost for one part is therefore 150/- and each subsequent part will cost 60/-. Allowing 20 minutes for loading, tool and tape changes the costs become 168/- and 78/-.

The cost for one part by conventional methods (35 hours working) is estimated at 525/-.

In this example the cost of computer-controlled machining is therefore 32 per cent of the cost by conventional means, and the utilisation of the tool is increased by a factor 30.

In this instance the part lends itself to copy milling once a master is available. It is interesting to note that the copy milling time is 12·4 hours representing a cost of 186/-. This should be compared with the figure derived above, of 78/- for subsequent parts on a computer-controlled tool.

The foregoing information is related to a small knee-type milling machine so that direct comparisons can be made. Spar and skin milling in the Aircraft Industry involves the use of much more expensive machine tools, the cost of the control equipment remaining unchanged. This will make the percentage cost savings with numerical control even greater.

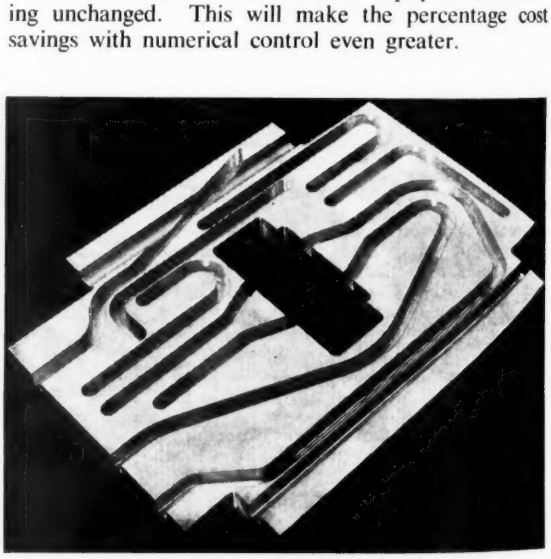


FIGURE 5. Milled block for electronic circuit.

PART 2

Introduction

The previous part of the paper has given an overall picture of a system of machine tool control which is unique in conception and the authors in this part would like to elaborate on the way that such a system has been achieved; in particular, to concentrate on the machine tool itself and to introduce the techniques which have been adapted to enable the system accuracy to be realised.

Servo-mechanism

Most members will be familiar with the background of servo-mechanism theory which has developed rapidly both before, during and since, the Second World War, especially in the field of fire control. There are two broad servo-control possibilities which can be applied on a machine tool. These can be divided as being essentially open loop and closed loop control of the actual machine slide movement.

Reference to Fig. 6 will show the essential difference between these two systems applied to the control of a machine tool axis. In Fig. 6(*a*), the machine movement is controlled through the agency of a precision lead-screw, the measurement of movement being taken by the rotation of this screw using a synchro or a photocell monitored disc. This can be defined as being open loop control of the slide. Fig. 6(*b*) shows a system of machine control whereby the actual movement of the slide is continuously measured and feeds back relative information to the servo-motor in order to maintain this movement to a given degree of accuracy.

In this work, attention has been concentrated on the control of machine tool slides in the manner as shown in Fig. 6(*b*). The merits of such a system allow for much greater accuracies of control than of the type in Fig. 6(*a*) and, indeed, the fidelity of the driving mechanism is much less critical. In each case the backlash of the machine elements must be rigidly controlled. With a good servo performance, it is possible to continuously monitor slides to $\pm 0{\cdot}0002$ in. using such a system, and it can be demonstrated that low frequency forcing vibration amplitudes on the slide during the milling process are reduced by the servo performance with direct benefits to machining accuracy and tool life, compared with that possible under open loop control. The compliance of the machine tool drive plays an important part in realising these potential accuracies in the milling process and considerable development work has been done in this field where servo-mechanism and vibration theories combine to set a challenging problem.

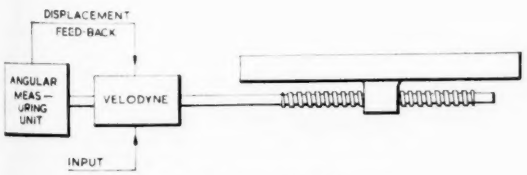


FIGURE 6(*a*). Open loop control.

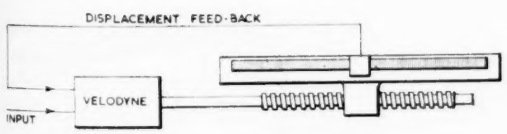


FIGURE 6(*b*). Closed loop control.

FIGURE 6. Block diagram of open and closed loop servo-system.

Technique of Measurement

In order to achieve the closed loop servo, a technique of continuous measurement must be adopted which as nearly as possible approaches perfection. A diffraction measuring system has been adopted which uses the Moire fringe effect to count fundamental digits of movement of the particular slide. Reference to Fig. 7 will illustrate the method of measurement using such a diffraction grating system.

The essential element of the measuring system is a length of optical diffraction grating carrying a line structure with a precisely known number of lines to the inch. The direction of the lines is at right angles to the length of the grating.

When two sections of such a grating are superimposed so that one is tilted slightly with respect to the other, a Moire fringe pattern with an approximately sinusoidal distribution of intensity is produced as a result of the integrated interference effects caused by the angular intersection of the individual lines on each grating. Effectively, this is a greatly magnified pattern in which the individual lines are easily separated. When one grating is moved with respect to the other, in a direction at right angles to its line structure, the fringe pattern travels at right angles to the direction of movement, the sense of this pattern movement depending upon the direction of relative travel of the two gratings. If a small portion of the pattern is inspected, it can be shown that a relative travel of one line width on the grating will cause a complete cycle of light and darkness on the interference pattern to pass the point examined. The width of the dark and light bands can be made sufficiently great to enable detection of individual bands to be readily achieved by the use of a photo-sensitive element. It will be seen, therefore, that if the number of dark and light bands passing a particular point, which can be defined by the position of the photo-sensitive element, are counted, a precise measure of the amount of displacement of one grating with respect to the other is obtained, providing the number of lines to the inch on a given piece of grating is known. For example, using gratings with 1,000 lines per inch a travel of half an inch will cause 500 interference bands to pass the point being inspected.

The photo-sensitive elements convert the light intensities into electrical signals of equivalent intensity. These waveforms are used to form a digital measuring system of two pulses per grating line.

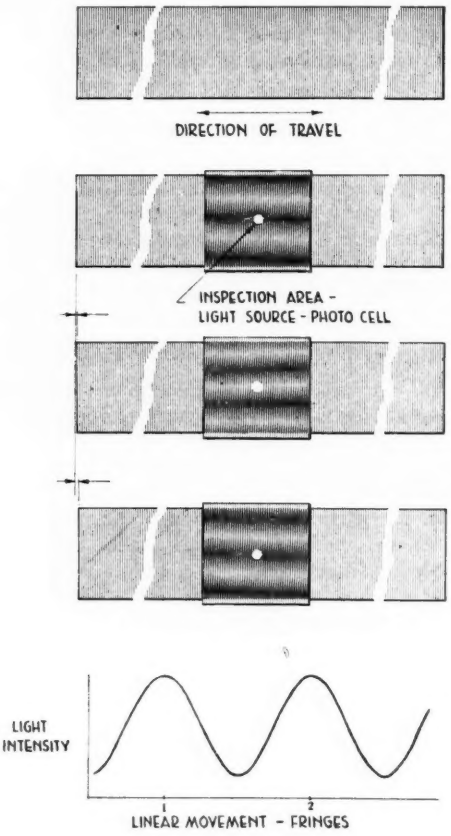


FIGURE 7. Diffraction grating showing Moire fringe patterns with light intensity distribution.

In order to discriminate direction, two points on the pattern are inspected. These are separated by an odd number of quarter wavelengths of the pattern and their outputs form a two-phase electrical system from which directional information is readily obtainable.

This measuring system is entirely free from friction or wear. Moreover, since information is being obtained from a relatively large area of grating, the interference pattern being an integration of a large number of intersections, lengths of grating can be placed end to end with small gaps if necessary. The absence of a few lines merely lowers the contrast of the pattern by a corresponding amount. By the same token, dust and scratches have little effect.

This measuring system fits into the displacement loop of the servo-mechanism as shown in Fig. 8. The digital pulse rate demand into the servo is transformed by the ratemeter into an analogue voltage proportional to frequency, this being applied to the magnetic amplifier. The servo-motor controlled by the amplifier drives both the machine table through suitable gearing and a precision tachometer. Signals from this tachometer are fed back into the amplifier to make a velocity loop servo system which is linear with pulse rate demand.

The demand pulse is also compared with the machine slide pulse rate output from the diffraction gratings at the register and the displacement differences are additive signals into the amplifier, to give an overall correction to the servo-system.

Drive Mechanisms

A high performance servo-mechanism has been developed to cater for machine tools up to a spindle horse power of 20. The servo-motors are three-phase, 400 c.p.s. induction motors delivering 0·7 b.h.p. at 10,000 r.p.m. and fed by high performance magnetic amplifiers. These motors are fitted with a magnetic drum brake to lock the slides when the motor is de-energised; this brake also operates as an emergency stop if the machining tolerances are exceeded, or when the limits of travel of the slides are reached. The motor drives through a back-lash-loaded gearbox, all gears being case hardened, profile ground, and journalled on needle bearings. Thrust loads are carried by taper-roller bearings. The whole reduction train is designed to provide long trouble-free service and to offer minimum inertia loading to the high-performance servo-motor. Lubrication is by oil mist, with the cast gearbox casing forming a sump.

The reduction ratio of the standard gearbox gives an output shaft speed of 100 r.p.m. at peak motor power. The output shaft is arranged to drive in three alternative planes to allow for variation of machine geometry, and a self-aligning torque-limiting coupling is fitted to safeguard the gearbox from overload. This couples on to the leadscrew, or other driving element of the machine, and it is recommended that backlash loading be employed on the machine feeds using, for example, recirculating ball leadscrews, in order to keep the transmission efficiency high under conditions of preload. This gearbox is illustrated in Fig. 9. Provision is made for carrying a rack extension gearbox on the

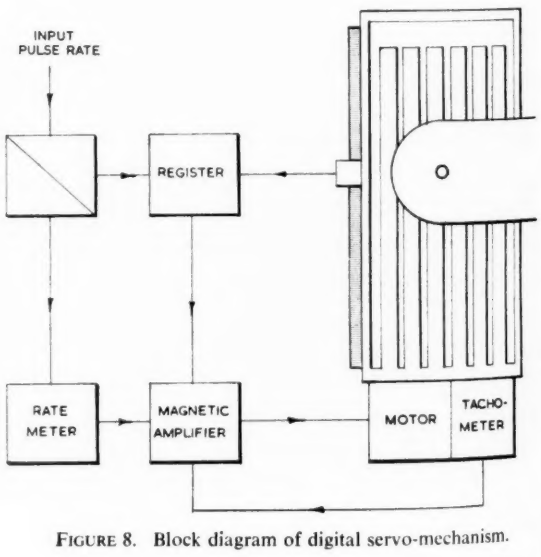


FIGURE 8. Block diagram of digital servo-mechanism.

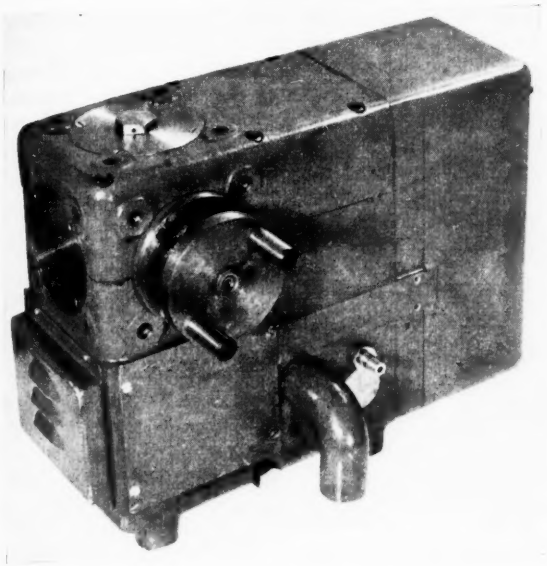


FIGURE 9. 0·7 h.p. servo-gearbox.

basic standard gearbox for the gantry type machine which lends itself to rack and pinion drive. This box is illustrated in Fig. 10.

Technique of Application

The application of this equipment to the knee-type miller has become fairly well standarised and, illustrated in Fig. 11, is the application to a No. 2 CE Kearney and Trecker milling machine. The table movements of the machine are equipped with the standard gearbox and diffraction grating measuring system. The drive is through recirculating ball leadscrews which are backlash-loaded to a level of 500 lb. on these two slides. The down feed of the machine is achieved through a special gearbox, which is again backlash-loaded, driving through a split quill nut on the head of the machine. The diffraction gratings on this particular type of machine are 2,500 lines to the inch, giving 0·0002 in. as the basic digit movement. The maximum continuous profiling speed is limited to 18 in. per minute with a basic computer to machine play-back ratio of 8: 1.

On the application to machines for profiling of light alloy and similar materials, usually the machine is of larger capacity and requires much higher profiling speeds than the knee-type miller. It is standard practice to use 500 line per inch diffraction gratings on these machines, giving a basic digit of 0·001 in. associated with either the standard gearbox driving through a leadscrew of one inch lead or, alternatively, through the rack extension gearbox to give a similar profiling speed of 120 in. per minute maximum. A two-dimensional profiling machine which is under development is illustrated in Fig. 12.

From the theoretical standpoint, it is desirable on all machine types to have freedom from backlash and low compliance on the drive. It can be shown that the

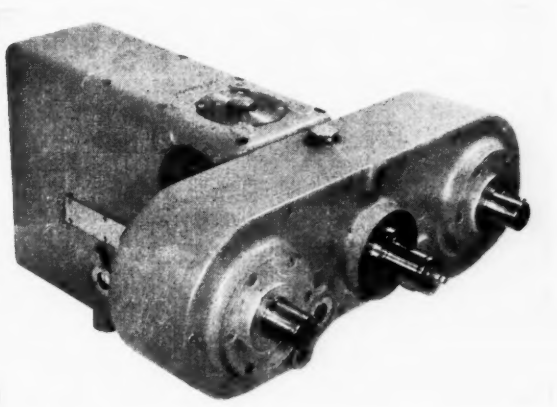


FIGURE 10. 0·7 h.p. servo-gearbox with rack extension.

reflected inertia of even a very large machine is only approaching that of the servo-motor inertia and, consequently, the servo performance is not appreciably affected in terms of rise time by machine masses. More serious, however, is the design of the reduction gearbox since lack of appreciation of the relevant factors here can add enormously to system inertia.

Friction in the machine drive is not a very predictable factor and servo-power is absorbed at the expense of overall system performance. By the use of rolling

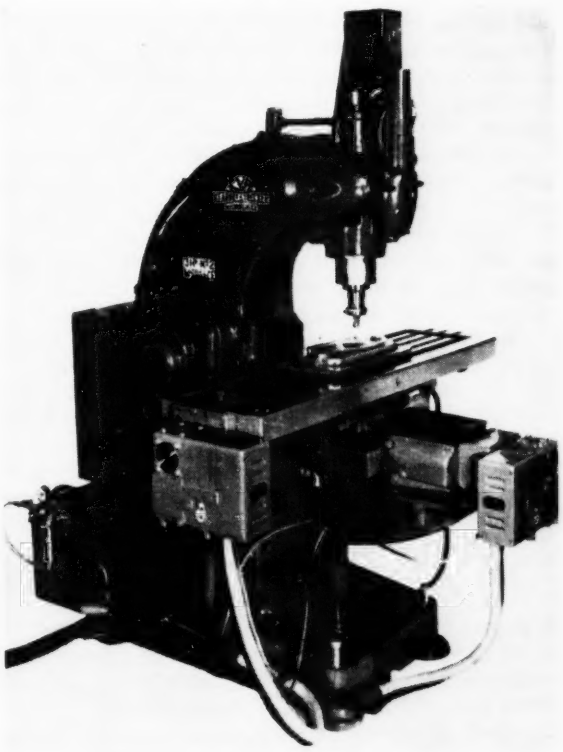


FIGURE 11.

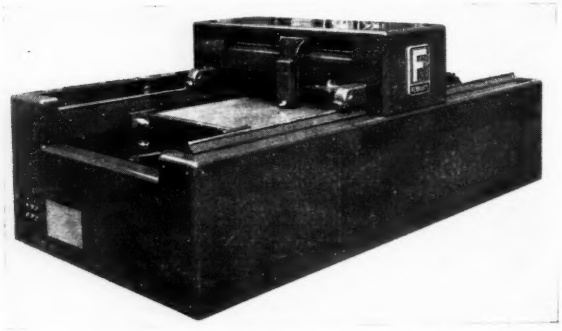


FIGURE 12. Two-dimensional profiling machine.

elements, or by hydrostatic means, it is feasible to reduce the friction level on machine tools down to a level where the servo is doing most of its work against cutting forces and acceleration demand. The transmission efficiency of the drive must also be as high as possible, and transmission elements at least as good as recirculating ball screws or rack and pinions are essential on controlled machine tools.

Much work needs to be done in this field and one of the main aims of this development programme is to cover all aspects of machine tool drive systems. The integration of high performance servo-equipment to specially designed machine tools will be achieved in the near future. The three-dimensional computer-controlled machine tool is already with us. It is now only a question of time before the fully integrated machine tool is ready to accept the full potential performance of the system, which includes the built-in additional machine function channels for the control of spindle speed, tool change, indexing and automatic jigging and fixing.

Active development work is proceeding on higher power servos for the very large machine tool. On theoretical grounds, at above 2 h.p., it can be shown that the hydraulic servo is potentially far superior to the equivalent electric servo, on the grounds of all-round performance and simplicity. Work up to the present time has confirmed this beyond question, and it is safe to predict that at the present rate of progress, hydraulic servos will have an increasing part to play at all power levels when the long-term reliability of components has been proven.

Conclusion

The magnitude of the development effort to the achievement of the system described has been very considerable, but the outcome is such that within a comparatively short time we shall see working in the industries of this country, electronic systems of control that will make a surprising change to the economics of machine work. This applies particularly to the capital goods industries where the manpower requirements, as a percentage of the overall cost, are very large. It will be seen that a revolution is occurring, the impact of which may, indeed, be second only to the introduction of mass production in industry.

ACKNOWLEDGMENT

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A New Concept in the Design of Jet Engine Mufflers and Test Cells

by

PROFESSOR E. J. RICHARDS, M.A., B.Sc. and D. J. EVANS, B.Sc.
(Department of Aeronautical Engineering, University of Southampton)

SUMMARY: A new concept is put forward which should help materially in the design of engine test cells and ground mufflers. It is suggested that a relatively small spreader can be added behind a jet nozzle which changes the shape of the jet from circular to a long annular slot. The frequency rise which may be obtained in this way is used to reduce low frequency noise, possibly at the expense of more easily attenuated high frequency noise. As a modest example, tests are described on one particular version which gives an attenuation in the most important low frequency range of nearly 20 decibels. It is shown that the back pressure on the engine is negligible even with a cooling flow equal to the engine mass flow. Other applications are discussed and tested, while suggestions for full scale installations are made.

1. Introduction

Research into the noise of aircraft jet engines carried out in this[1,2] and other countries during the past few years has provided a framework on which to estimate the likely noise levels on new designs currently being developed and the reductions to be obtained by such devices as corrugated jet pipes[3,4] and the like. The outcome of such examinations can hardly be reassuring, however, and it is likely that the noise problem will become more rather than less severe during the next five years. The general trend, apart from that on such engines as the bypass Rolls-Royce Conway with its low average efflux velocity, is to higher pressure ratios and consequently higher outlet velocities. The general introduction of afterburning increases the efflux velocity greatly so that noise levels well above those now prevalent may be expected from military aircraft. The use of convergent divergent corrugated nozzles cannot be expected to give much alleviation away from the design range[5], and the optimum design condition may well be chosen as a flight case in view of the even more serious effect of the noise on structural vibration[6,7]. The need for both elaborate ground test cells and mufflers, both portable and permanent is therefore likely to increase.

The purpose of this paper is to introduce a new concept into the design of such units which eases the difficult low frequency problem, which allows a lighter, cheaper, construction to be used and which provides a new type of portable muffler devoid of any silencing material as such. The work reported here has been carried out at the University of Southampton with financial aid from the Cementation (Muffelite) Company, England.

2. Present Ground Silencing Methods

Present sound mufflers and test cells are so varied in design that it is difficult to place them into categories. The two diagrams of Fig. 1 outline the features of the two essentially different types, now found in various countries. In all cases the basic difficulty has been the sufficient attenuation of the low frequencies between 50 c.p.s. and 400 c.p.s. Thus in type A, mass is added to the building, suitably constructed splitter baffles (often several sets) are so placed as to attenuate certain low frequency ranges. The funnel incorporated in many of these designs is aimed at inducing cooling air into the jet. The detuner type of muffler of type B consists of taking the jet gas into a long legged pipe arranged with baffles to detune the lower frequencies. The large mass of the units causes much attenuation, the attenuation in the very low frequency range, a typical example of which is given in Fig. 2, is however very seldom more than 15 decibels. In no case has there been any attempt to modify the jet and alter its sound emitting qualities. The approach is rather that of "let the jet make its noise—then let us silence it." This has arisen to some degree from the engine designer's insistence that the muffler or cell must not interfere with the performance of the engine; this requirement is kept in mind in the proposals put forward later.

The concept developed in this paper is essentially that which follows from a full understanding of the nature of the noise source; the jet is directed, without back pressure, into a unit in which it is so reshaped as to give rise to a much smaller low frequency noise content. Before describing the devices, it is proposed to examine the source of jet noise in detail in order to exploit this jet modification possibility to the full.

3. The Nature of Jet Noise

Jet noise is that caused in the region of mixing of a jet of moving gas with the external air, and arises from the presence of turbulence or some other non-steady motion. By definition[8] it excludes mechanical noise coming from the interior of the engine but does include noise generated by any burning of fuel after it has left the jet nozzle and from any initial turbulence set up

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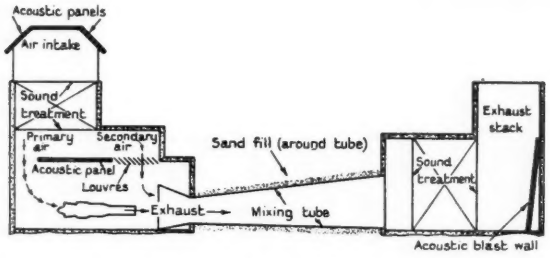


FIGURE 1 (*scheme a*). Typical modern engine test cell (from Ref. 15).

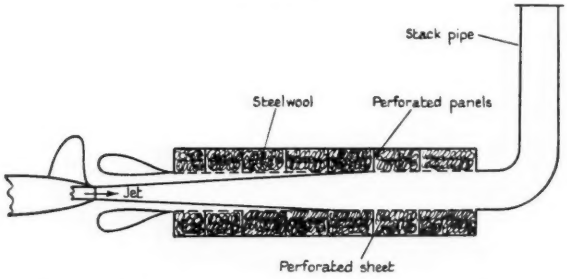


FIGURE 1 (*scheme b*). Ground muffler type of silencer (diagrammatic).

inside the jet pipe by this or other means. This latter source of noise while large on primitive forms of jet unit[9], can usually be neglected on modern gas-turbine engines. Even with reheat, there is no indication (from a change in the noise law) of any serious increase of noise due specifically to residual turbulence and delayed combustion.

Generally, therefore, jet noise arises from the turbulence which is set up while the gas mixes with the surrounding air. It is amplified greatly if this turbulence occurs in a region of high velocity shear, for instance, either close to the nozzle exit where the velocity in the jet direction falls very quickly across the jet edge, or as it passes through a stationary shock aft of a choked nozzle. Thus it has been found convenient to think in terms of three sources of noises:

(*a*) that from the interference between turbulence and the standing shock pattern,

(*b*) that from the mixing region close to the jet, in which the noise is amplified by the presence of the region of high velocity shear,

and (*c*) the noise downstream where the mixing region has spread across the entire jet and no large velocity shear occurs.

This simplified model of the noise source is useful in that it allows us to differentiate between high and low frequency sources; typically the wavelength of the sound emitted from any mixing region must be related to a length equal to or less than the geometrical width of the region, since this defines the maximum depth of the mixing "eddies." Thus in Fig. 3, which gives a diagrammatic representation of a circular jet, the high

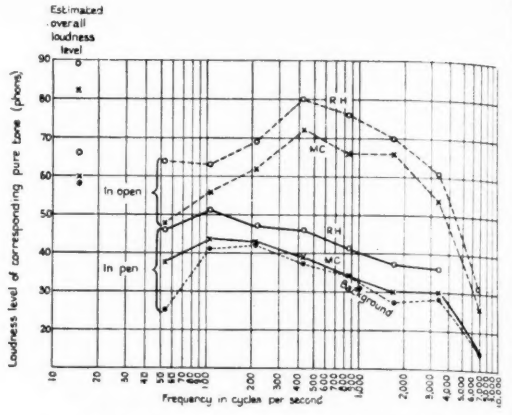


FIGURE 2. End of cross runway 1,000 yd. Typical example of the jet noise attenuation from a muffler and pen (Ref. 16).

frequency sound will emanate from the region (*b*) in which the dimensions of the mixing region are small while, typically, the low frequency sound will emanate from region (*c*) where the "eddies" can extend the whole width of the jet. Thus it is a matter of experience that the majority of the low frequency noise is formed well downstream, while the high frequency content arises from the region close to the nozzle. The shock interference noise emanates from the places where the shocks occur, the frequency being related typically to the wavelength of the eddies passing through the shocks[10].

Noise suppression at source must rely on the elimination or reduction of these "eddies" or regions of turbulence and is extremely difficult to do in a mixing jet. Existing methods[4,8] rely on increasing the mixing rate while preventing any increase in the initial turbulence. For example, the corrugated nozzle shown in Fig. 5 is so arranged that when the region of mixing has grown to half the width between the corrugations, the relevant mixing region dimension changes to that of the whole depth of the corrugation. Thus "eddy" wavelengths normally attributed to that part of the mixing region of dimensions between these two values are eliminated and (as shown in Fig. 5) an appreciable noise reduction in this frequency range is obtained.

The scope for such reductions, limited on a jet nozzle itself, can clearly be very large on ground installations where the shape of the jet can be modified extensively by suitable devices. Consider for example a jet of gas which flows from an annular or peripheral nozzle of the same cross-sectional area as that in the circular nozzle of Fig 4. The mixing region length will of course be reduced in the ratio l/d and the width of the jet at the point downstream where the velocity has been reduced to one half, for instance, will be similarly reduced. Thus a general raising of frequency will occur which, with a normal jet spectrum, will result in a noise suppression in the lower frequencies and in an increase at the very high frequencies. Since in the one case the noise will vary as d^2 while in the other it will vary with

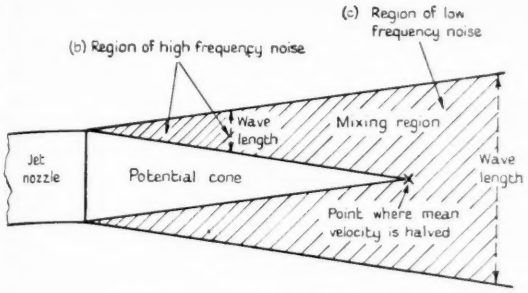


FIGURE 3. Diagrammatic representation of sound sources in circular jet.

$l \times 2\pi r$ (*i.e.* in both instances as the cross-sectional area) it is unreasonable to expect an overall reduction in noise; nevertheless a device of this sort which essentially alters the distribution of noise in the spectrum is most beneficial particularly as the higher frequencies are more easily attenuated[11] both by the atmosphere and by soundproofing material.

4. Forms of Silencer

The above concept requires an extension which changes the jet from circular into a long slit either in the way mentioned above, or by other means, without the introduction of any initial turbulence. The longer the final slit, the higher will the frequency be raised. An additional reduction at any frequency may, of course, be obtained by adding suitably designed corrugations, along the length of the slit, as indicated in the introduction.

Since only very high frequency noise emanates from very near to the jet itself, it is not an essential part of the concept that the jet be attached directly to the extension unit. Indeed the tests referred to later show that little efficiency is lost in the low frequency range when quite a large inflow is allowed. Fig. 6 shows four practical applications of the above concept. The relative advantages and disadvantages may be listed as follows.

Scheme (*a*) *The Fishtail*

This arrangement typifies the simplest application of the system. There is no need for a central core, so that heating difficulties are eased. There need be little overall load on the unit if the viscous forces are counteracted by a slight expansion in the unit and a corresponding change in static pressure distribution. Thus by careful design, the unit can be made portable with little load on it as a unit and with (as shown later) a negligible back pressure to affect the engine performance. In the tests carried out on this configuration, it has been found that in practice, however, considerable trouble occurred in the shaping of a unit to obtain a full flow. Any breakaway of flow arising from too severe a change of shape from circular to slit results in a greatly increased initial turbulence and a noise amplification. The unit therefore needs to be longer than with others, a short unit only being feasible with

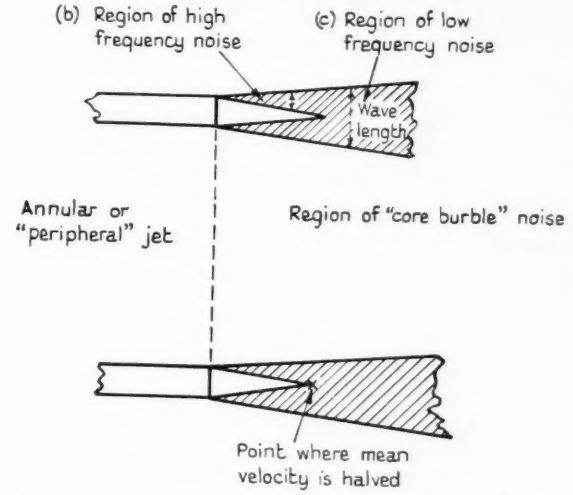
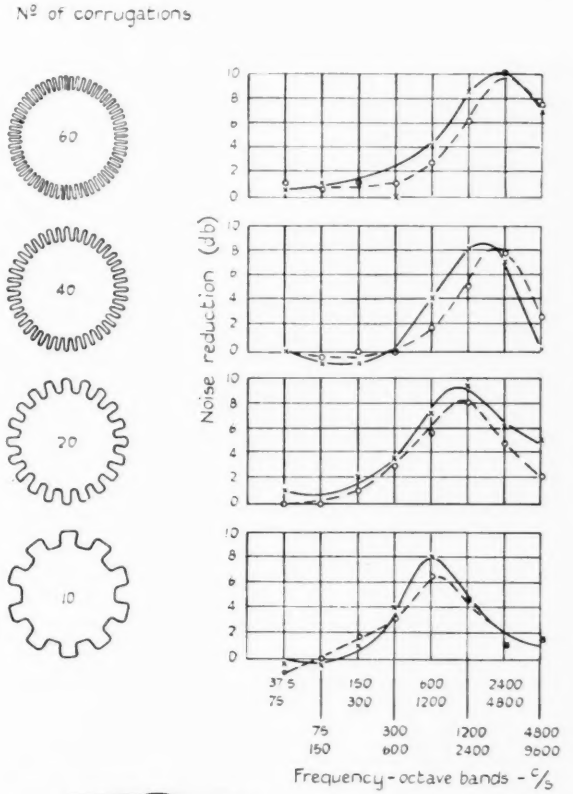

(b) Region of high frequency noise
(c) Region of low frequency noise
Wave length
Annular or "peripheral" jet
Region of "core burble" noise
Point where mean velocity is halved

FIGURE 4. Diagrammatic representation of sound source on peripheral or slit jet.



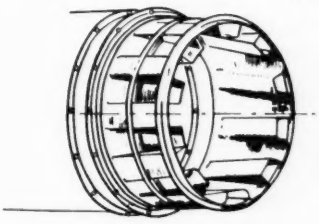


FIGURE 5. The attenuation of noise using a corrugated nozzle. Noise measured at 50 ft. radius. ×———× 15° from jet axis. o——o 30° from jet axis. Jet velocity 1,800 ft./sec.

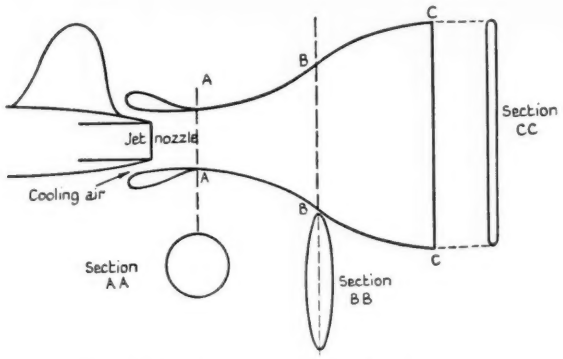


FIGURE 6 (*scheme a*). The fishtail (elevation).

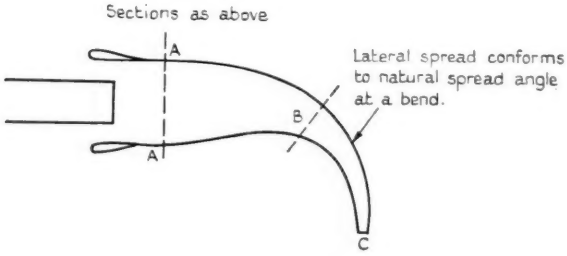


FIGURE 6 (*scheme b*). The bent fishtail (plan).

the aid of guide vanes, an addition which presents heating and burning problems.

Scheme (*b*) *The Bent Fishtail*

Flow breakaway can be eliminated on a short unit by combining the fishtail in a bend, the rate of spreading being related to the natural tendency for the flow to spread at such a bend. Such a unit, which can be made quite short does involve some amount of heating of the skin although no sharp edges protrude. There are of course forces equivalent to the engine thrust acting on the unit; it is therefore unsuitable as a portable installation but can be used ideally for permanent vertical rocket arrangements or incorporated into engine test cells.

Scheme (*c*) *The Peripheral Spreader*

A rapid method of spreading which allows a far quicker derivation of a long thin slit jet is that obtained by using the axial spreading arrangement of Fig 6 (*c*). As indicated later, the pressure distribution throughout such a device can be calculated precisely and can be chosen in such a way as to eliminate any danger of flow breakaways. The device can be designed to have zero or little force on it as in scheme (*a*) by expanding slightly to counter the viscous drag of the walls; it can be designed to give a negligible back pressure on the engine. Thus it is suitable as a small lightweight portable ground muffler with little overall load and negligible effect on engine performance, suitable for testing engines before flight or as a part of a more elaborate engine test cell. In view of its lightness, it

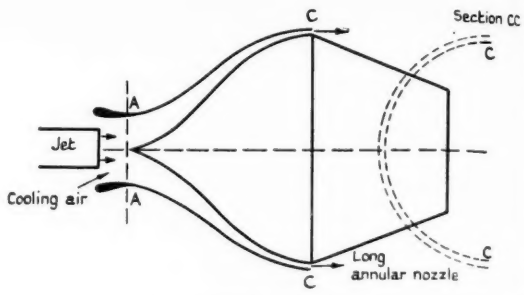


FIGURE 6 (*scheme c*). Peripheral spreader.

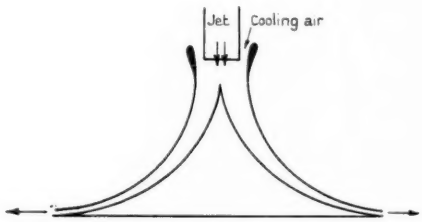


FIGURE 6 (*scheme d*). The right-angled peripheral spreader.

can be moved about in a test cell to accommodate varying bent jet pipe configurations.

However, it has the disadvantage of having a central core which must be suitably designed to withstand the temperatures involved. With reheat, this probably means water cooling. On the other hand the narrowness of the slit suggests that water injection in the final part of the spreader should be very efficient. Experiments have shown[12] that the mechanism of noise suppression by water injection is chiefly the addition of mass to the jet and so the reduction of velocity for a given thrust. Thus a system in which the water spreads uniformly throughout the gas, thereby reducing velocity uniformly is likely to give better results than hitherto obtained. In the event of water being used, water jacketing of the nose of the core, before its injection into the stream, would appear to be the optimum arrangement of a practical system, particularly one capable of dealing with reheated engines.

Scheme (*d*) *The Angled Peripheral Spreader*

This development of scheme (*d*) may be more useful for incorporation into test cells in which the engine unit is mounted vertically. The spreading can be more rapid than in scheme (*c*) while the need, already there, to change the direction of the jet is utilised for noise suppression. Water injection can be added efficiently as proposed above, and the whole incorporated into a test cell installation for rockets and so on. Although the load on the spreader is equal to the thrust of the engine in this case again, some such deflecting device would be required in any installation.

None of these suggested installations has been shown to incorporate corrugations. In any practical installation, any available device aimed at still further

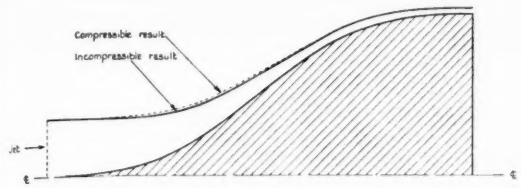


FIGURE 7. Mathematically designed 3:1 radial spreader without cooling.

reducing the noise from the slit jet would naturally be included on its merits. Furthermore, each system has been described as effectively having a constant velocity throughout its length. In practice, on fixed units in which the load on them does not matter, as much diffusion as can be made without flow breakaway would clearly be beneficial in order to lower the final efflux velocity.

5. The Peripheral Spreader

At the beginning of this investigation, the greatest need was for an easily portable muffler to provide a modest noise reduction on an un-reheated engine. For this reason and because the type lends itself more easily to mathematical analysis, most of the work described here is confined to the peripheral spreader indicated in scheme (*c*). Some measurements of noise were made on a device similar to scheme (*a*) but no measurements of back pressure were made. This is described in Section 9.

In view of much previous experience on the serious noise increase if breakaways in the flow occurred, pride of place in the investigation was placed in obtaining a spreader in which the adverse pressure gradients at all points are less than those in a straight conical diffuser of 7° angle. No attempt was made at this stage to obtain cooling air, the extension fitting smoothly the jet nozzle with the modest spread achieved by a radius increase of ratio 0·3 to 1.

Two methods were used to obtain such a design. First an inside shape was chosen arbitrarily and the outside wall calculated to give a constant area normal to the mean line of the flow; the pressure distribution along these walls was then calculated by a relaxation technique[13] and the adverse pressure gradients examined. Where the gradients were larger than could be tolerated, empirical modifications to the length and width of the duct were introduced and a check made on the pressure distribution. This procedure was continued until a satisfactory pressure distribution was obtained.

A second and parallel experimental investigation[13] was carried out in an electrolytic tank suitable for investigations on bodies of revolution; here again the wall shapes were modified in the light of the potential flow distribution until acceptable pressure gradients were attained. The final shape obtained is given in Fig. 7 for a spread of three-to-one on radius aimed at a three-octave increase in frequency.

6. Noise Measurements on a Peripheral Spreader

Since these calculations were prolonged, the first preliminary noise measurements were made on a peripheral spreader whose outer boundary was designed on the constant area basis, mentioned above as the starting point. There was no cooling flow between the jet nozzle and the spreader, nor were there corrugations along the final slit. Octave analyses of the noise at various pressure ratios and nozzle velocities are compared in Fig. 8 with those on a circular jet at the same mass flow and thrust. It is seen that in spite of the fact that the pressure along the duct was only approximately constant so that some separation of flow was to be expected, the noise reduction is appreciable and substantiates the arguments of the dimensional theory. In particular, at a typical point 30° to the line of the jet and at a distance of 25 diameters (of the circular jet) in the expected direction of greatest noise, and on a basis of equal thrust and velocity:

(*a*) The noise spectrum is raised by about 2·5 octaves in frequency at the highest velocities. This compared well with the expected figure of 3 octaves

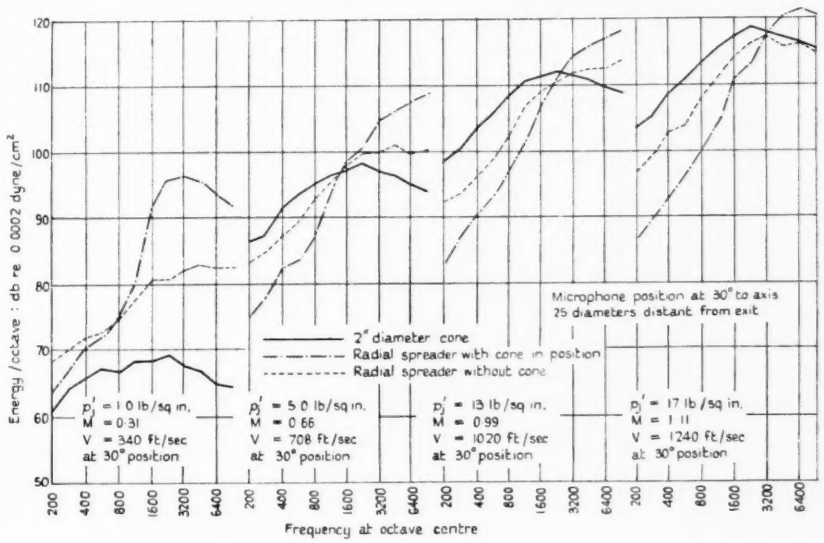

Energy / octave : db re 0·0002 dyne/cm²
Frequency at octave centre
Microphone position at 30° to axis
25 diameters distant from exit
2" diameter cone
Radial spreader with cone in position
Radial spreader without cone
p'j = 1·0 lb/sq in.
M = 0·31
V = 340 ft/sec
at 30° position
p'j = 5·0 lb/sq in.
M = 0·66
V = 708 ft/sec
at 30° position
p'j = 13 lb/sq in.
M = 0·99
V = 1020 ft/sec
at 30° position
p'j = 17 lb/sq in.
M = 1·11
V = 1240 ft/sec
at 30° position

FIGURE 8. Comparison of spectra for 2 in. diameter jet and radial spreader.

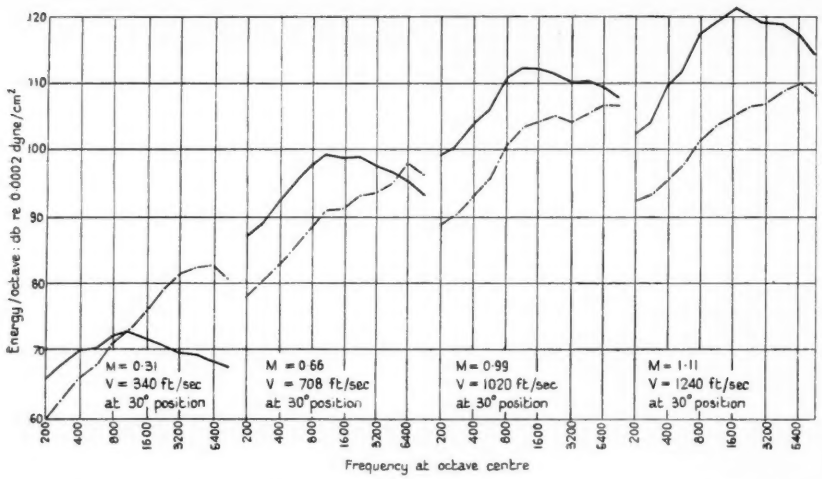


FIGURE 9. Comparison of spectra from jet and radial spreader at various exit velocities.

and allows us to predict the frequency change which arises from the use of still thinner slits.

(*b*) At the lowest frequency the noise is reduced by 15 decibels at a Mach number of 1·1.

(*c*) There is a reduction of 14 decibels in the frequency ranges of 600-1,200 c.p.s. at the same Mach number, corresponding to the take-off conditions of the engine. Allowing for the frequency reduction due to scale, which varies inversely as the diameter, a noise reduction of the same order can be expected in full scale at frequencies in the range 50-200 c.p.s. by a 3:1 spread system. If a greater spreading and a corrugated exit are introduced, this frequency range can be raised to any required region.

(*d*) At the low values of the jet speed (*e.g.* $M=0{\cdot}31$) there is a noticeable deviation from the above findings, the noise spectrum indicating an increase in low frequency noise above the noise of the circular jet. This arises from the large scale burbling occurring inside the core of the annular jet. This was overcome by the introduction of a solid base cone of total angle 15° to fill the turbulent air core. This has the required effect, the dotted curve in Fig. 8 showing the improvement. Further investigation shows that this angle can be increased to 20 degrees half angle without serious increases in the core noise.

In view of these satisfactory results, a more extensive analysis was made with a spreader designed mathematically as described and with a shape given in Fig. 7. Comparisons between this unit and a circular jet of the same area are given in Fig. 9. The same type of gains are to be seen as on the preliminary design. One difference is apparent, however, which should be commented upon. At a jet velocity of 1,240 ft./sec. and $M=1{\cdot}11$, the low frequency attenuation is slightly less than before (10 decibels). The reduction in the 600-1,200 c.p.s. range, the most important range bearing in mind scale effect, is nearly 20 decibels, a larger figure than in the preliminary tests. Furthermore, there seems to be no cross-over point as would be expected. This will be referred to later.

As these results refer only to a single point in space, examinations of the overall noise fields have been made by integration of the spectra, and compared with similar field contours obtained for the circular jet. It must be pointed out that these measurements were made in a confined space and have been corrected[13] to free air conditions. Thus while they are accurate enough for comparison one with the other, they cannot satisfactorily be compared with other field measurements made in entirely different surroundings. In Figs. 10 (*a*) and (*b*) and Figs. 11 (*a*) and (*b*), these overall noise fields are compared for two pressure ratios, corresponding to jet efflux Mach numbers of 0·66 and 0·99. The latter comparison which relates closely to the conditions on a jet engine at take-off conditions, indicates similar noise fields in both instances, the overall noise reduction being maintained in all points of the field. Figure 12 shows the total acoustic power transmitted from the two units. At the low efflux velocities, it will be seen that there is an increase in overall power emitted, presumably owing to the preponderance of "core burble" noise, even with the shortened core in place. At the velocities representative of take-off conditions, however, there is a seven decibels reduction in the overall acoustic output.

The eighth power law holds very well for the circular jet, whereas a power law of V^5 is obtained on the peripheral jet. This indicates a source of sound other than that normally obtained in a jet, either arising from some initial turbulence which lessens as the jet speed increases, or from the core noise. The fact that the shape of the overall noise—velocity curve has increased appreciably by the introduction of the central cone suggests that much of this arises from "core burbling" and not from initial turbulence.

With reference to the high frequency output, an examination of the curves indicates less high frequency noise than would be expected. Indeed in Fig. 9 at a jet speed of 1,240 ft./sec., the high frequency noise of the circular jet has not been exceeded even though the noise of the peripheral jet has passed its peak. This cannot be explained by dimensional arguments and remains as a point to be investigated in the full-scale unit now being made.

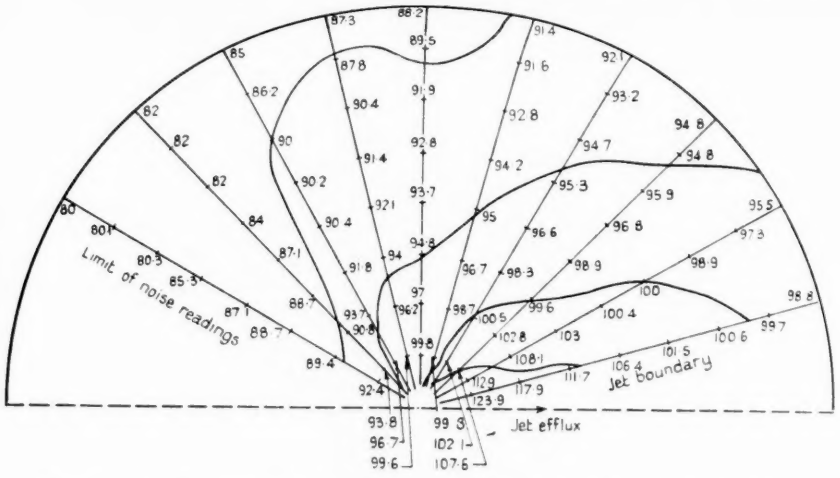


FIGURE 10(*a*). The near noise field from 2 in. diameter jet; $p_j' = 5$ lb./in.^{2}, $M = 0{\cdot}66$.

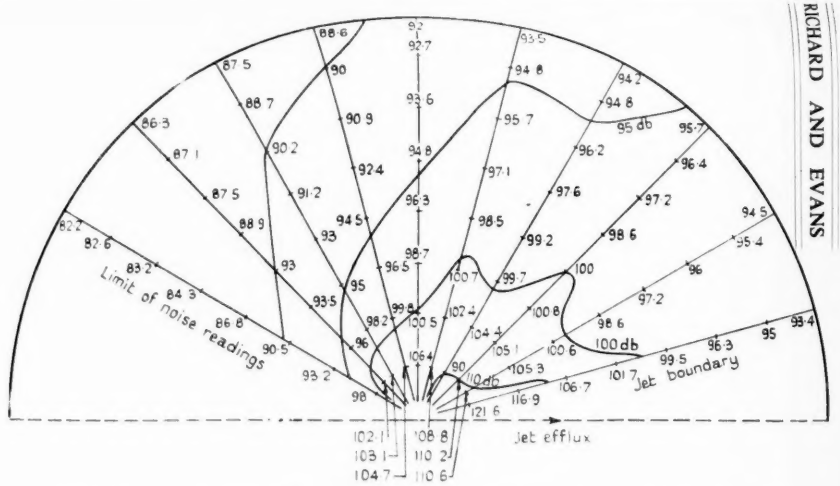


FIGURE 10(*b*). The near noise field from radial spreader; $p_j' = 5$ lb./in.^{2}; $M = 0{\cdot}66$.

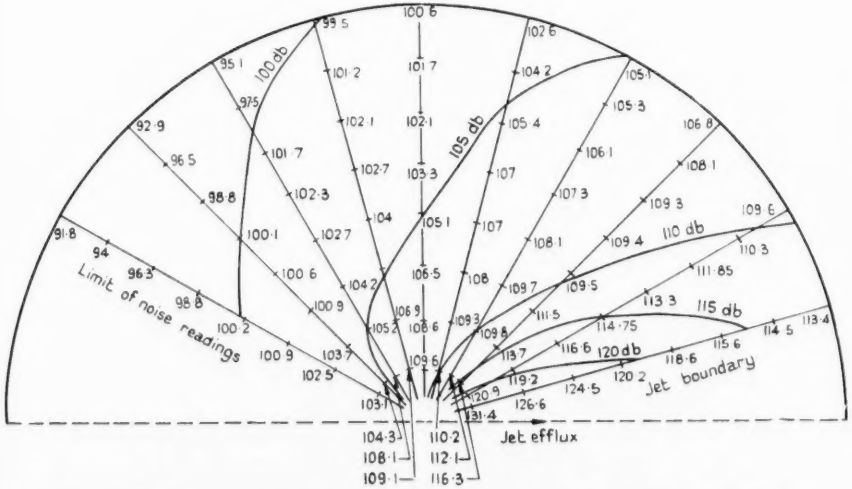


FIGURE 11(*a*). The near noise field from 2 in. diameter jet; $p_j' = 13$ lb./in.^{2}, $M = 0{\cdot}99$.

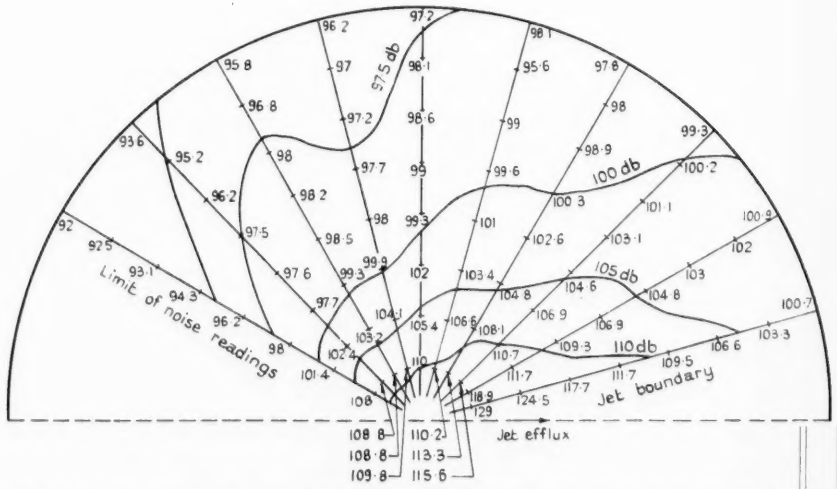


FIGURE 11(*b*). The near noise field from radial spreader; $p_j' = 13$ lb./in.^{2}, $M = 0{\cdot}99$.

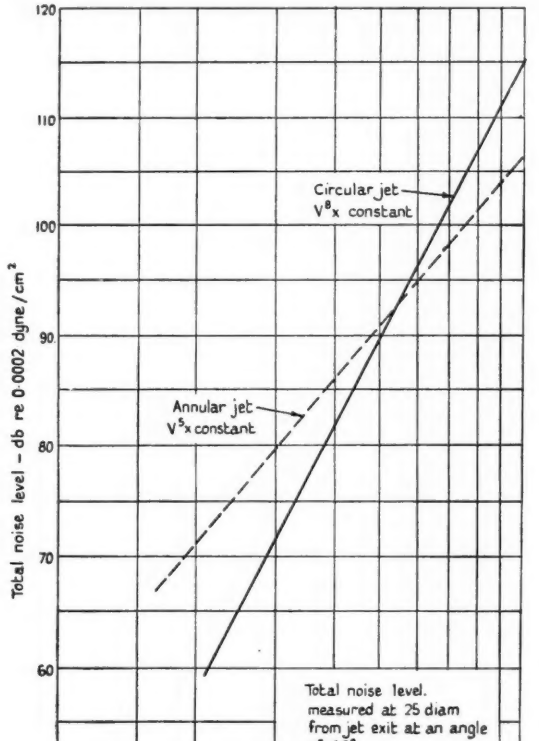


FIGURE 12. Variation of noise level with exit velocity of circular jet and annular jet. (Jet and peripheral spreader.)

7. Cooling Air

The aforementioned tests were made with the extension attached smoothly to the nozzle in order to provide a true comparison between the noise of circular and annular jets. Such a system cannot, however, be envisaged in a practical application, as it may modify the engine characteristics for the same thrust and in any case would detract seriously from the practicability of the device. Furthermore it is generally necessary to add cooling air to the jet in order to reduce the burning effects of the hot gases. Thus a major step in the development of this concept of the long slit jet extension has been the effect on noise, back pressure, and cooling of a change to a loose fit arrangement which will be acceptable as a practical muffler or part of a test cell.

A model of a practical unit (whose general shape is shown in Fig 13 (*a*) and whose details are given in Fig. 13 (*b*)) has therefore been developed and measurements made of noise, pressure across the mouth and cooling mass flows. The unit has a trumpet-shaped mouth leading into a section whose area in the initial parallel position is 3 times the jet nozzle area. This area is then kept constant and a spreader design calculated in the same way as that described previously.

Theoretically[13] this gives a unit which induces a mass of air equal to that of the jet and which mixes completely in the length of the spreader extension. Thus we have an essentially different arrangement from that previously described. The velocity from the annular jet is half that of the nozzle; on the other hand the turbulence is increased very considerably in the mixing process while noise, particularly high frequency noise, is emitted from between the jet nozzle and the spreader unit.

Noise measurements for a range of pressure ratios are plotted against wind frequency in the octave band in Fig. 14, and are compared again with those of a circular jet at the same pressure ratios. It is seen that at jet speeds representative of take-off conditions (*e.g.* 1,240 ft./sec.) the noise reduction is maintained at the low frequency range although the reduction is not as great at high frequencies. This high frequency increase arises from the noise emitted from the gap between the jet nozzle and the spreader and can only be eliminated by closing the gap or by sound-proofing the area. Its frequency is high however, as would be expected near the nozzle, and it can be attenuated by other means.

Some comment is necessary regarding the maintained level of suppression at the low frequencies. At first sight, a still greater reduction might have been expected in view of the reduced velocity from the old nozzle. Further examination of the sources of noise quickly dispels this fallacy however. The same mass flow of air is involved and the low frequency noise is generated only when full mixing has occurred (*i.e.* well downstream). Thus the effective source of low frequency noise is the same in both instances; it would have been necessary to have built a new spreader with roughly twice the spread diameter and the *same* slit width as that of the existing uncooled spreader to have obtained a reduction equivalent to that expected by the velocity reduction. In practical installations, this course

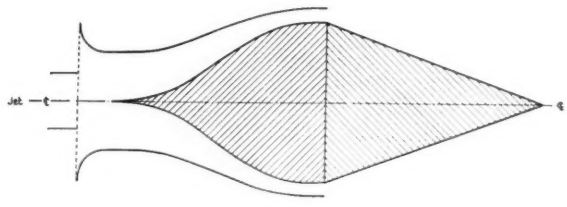


FIGURE 13(*a*). Radial spreader showing wooden cone and mounting position in relation to jet.

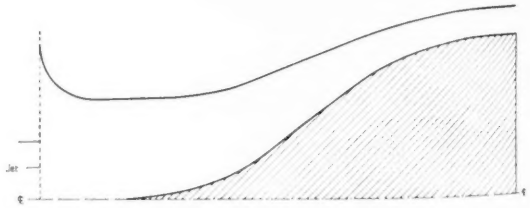


FIGURE 13(*b*). Radial spreader with cooling.

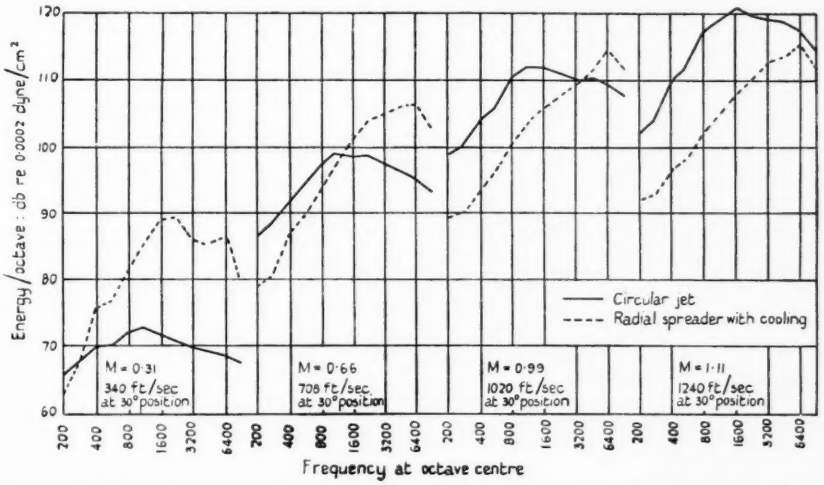


FIGURE 14. Comparison of spectra of jet and radial spreader with induced flow ratio 1/1 at various exit velocities.

is to be recommended; the final width of the slit being dictated by the size of the final peripheral jet nozzle involved and by the need to suppress mostly the noise at frequencies up to 300 c.p.s. or more.

At lower pressure ratios, the same general characteristics are to be noticed as before, although here again the peripheral spreader shows seriously adverse qualities at low speeds, for example at 340 ft./sec. in Fig. 14. This is again probably due to the high level of "core burble" noise always present.

Figures 15 (*a*) and (*b*) show the overall noise fields from the spreader with the one-to-one mass flow cooling. These have been obtained by integration of the spectra at various positions around the jet. It will be noticed at once that these differ considerably from those of the uncooled spreader, the large high frequency noise content emitted from the trumpet region adding greatly to the overall noise levels in the forward direction. Indeed a total summing of the acoustic power output from the jet in the presence of the cooled air spreader shows that the 7 decibels overall suppression previously referred to without cooling has disappeared

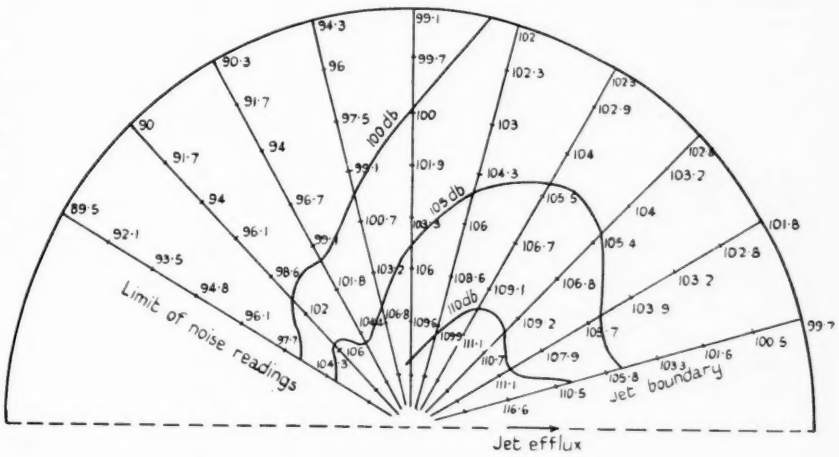


FIGURE 15(*a*) (*right*). The near noise field from radial spreader with induced flow; $p_j' = 5$ lb./in.², $M = 0{\cdot}66$.

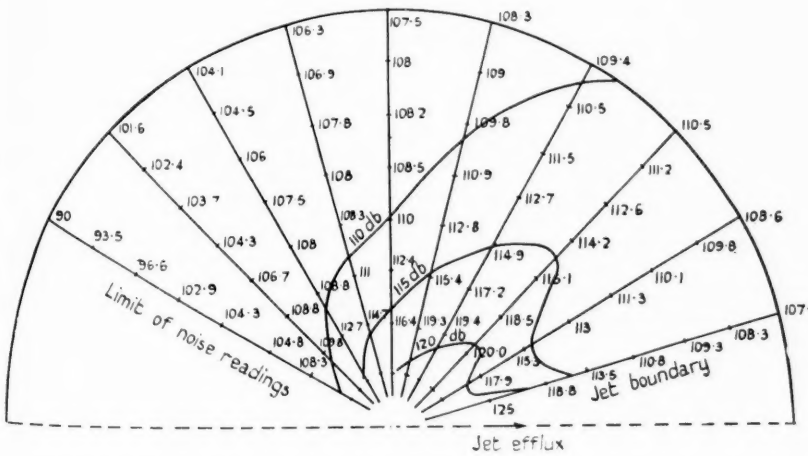


FIGURE 15(*b*) (*left*). The near noise field from radial spreader with induced flow; $p_j' = 13$ lb./in², $M = 0{\cdot}99$.

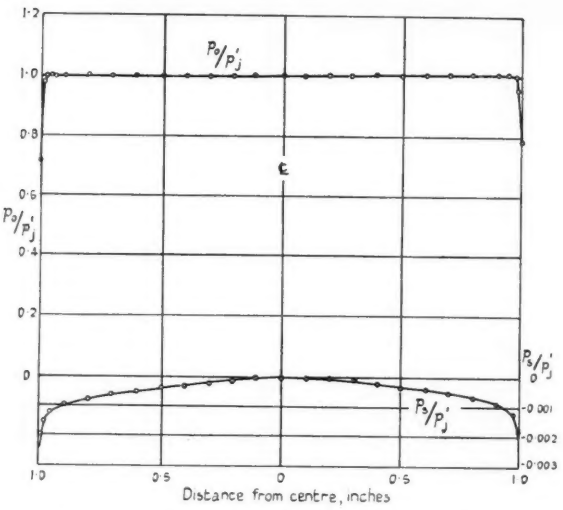


FIGURE 16. Traverses across 2 in. diameter jet exit in presence of radial spreader; $p_j' = 13$ lb./in.^{2}, $M = 0{\cdot}99$.

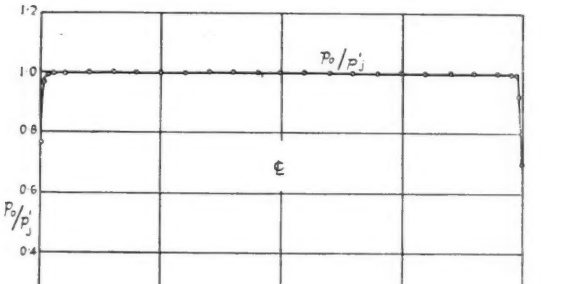


FIGURE 17. Traverses across 2 in. diameter jet exit in presence of radial spreader; $p_j' = 5$lb./in.^{2}, $M = 0{\cdot}66$.

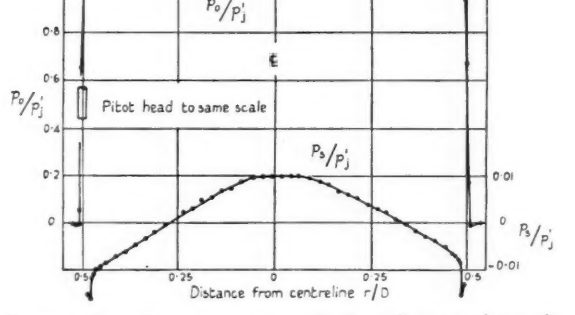


FIGURE 18. Traverses across 2 in. diameter jet exit; $p_j' = 5$ lb./in.^{2}, $M = 0{\cdot}66$.

entirely. There should be no difficulty in attenuating this high frequency output in test cells. On portable mufflers on the other hand, the advantage of adding a screen of high frequency soundproofing material fairly close to the trumpet needs to be considered.

8. Back Pressure on the Engine

In deriving a satisfactory practical form of spreader two major requirements have been considered in addition to that of noise suppression. The first, already referred to, is the need for a loose fit of the spreader to induce cooling air and to provide a practical method of fitment, the second is the need for a unit which when present does not interfere with the engine performance in any way. In the experiments, the intake was designed to obtain an amount of cooling air equal to the mass flow of the jet for a wide range of conditions. The method of design given in Ref. 13 is not critical, however, and is not dealt with extensively in this report. Efficient design for cooling is, however, closely related to zero back pressure, our second requirement.

For a jet engine to give the same performance with and without the spreader in position, it is necessary to ascertain on the model that for a given pressure ratio in the engine, the static pressure at the jet exit and the total head distribution are unaltered by the presence downstream of the spreader.

In Fig. 16, these figures are given for an excess pressure p_j' of 13 lb./in.^{2} equivalent to a Mach number of 0·99 (*i.e.* with the jet pipe just below the choking condition). It is seen from the traverse of p_o, the excess stagnation pressure above the ambient room static pressure, that this remains equal to the internal pressure in the pressure chamber as with a circular jet on its own. The profile is unaltered by the presence of the spreader indicating no modification of the general flow pattern. More significantly the lower figure shows that p_s, the difference between the static pressure and that of the atmosphere, is less than one per cent of the internal excess pressure at all points except very near to the edge of the jet and for the majority of the jet is within one half of one per cent of the ideal condition. Similar figures (Fig. 17) to the above have been obtained at lower pressure ratios, as would be expected. They are very similar to those measured previously[14] on a circular jet (Fig. 18) with no spreader in position. Since a jet engine is not sensitive to such small back pressure variations, a well-designed spreader can clearly be used not only for portable ground mufflers but can also be incorporated in engine test cells in which the derivation of engine performance figures requires a unit which leaves the engine characteristics unimpaired.

No measurements have been made at higher pressure ratios in which the jet will become choked. The degree of choking to be obtained in normal ground runs is not very great however and the above conclusions will probably hold. Engines become severely choked however in altitude conditions; the effect of such a spreader in tests simulating altitude effects, therefore, needs further consideration.

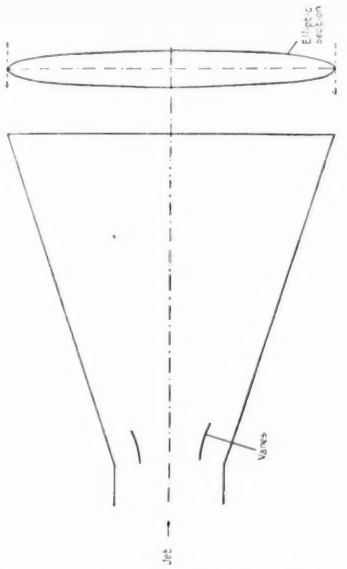


FIGURE 19. Fishtail unit with turning vanes.

9. The Fishtail Unit

The great disadvantage of the peripheral spreader is of course the need for a centrebody. This must be made of stainless steel and for tests with reheat, cooling will be necessary. At first sight therefore the fishtail arrangement has every advantage. During the development of such a unit, certain difficulties have been met however which are well worth recording, even though work on this type of spreader is not showing great promise. The chief difficulty is that of making the duct flow full at all stages while still keeping it short. Fig. 19 shows a fishtail unit tested in the laboratory; at first the addition of this unit increased the noise by resonance of the flat walls of the slit duct. This was overcome by heavy bracing of the skin and the noise reductions of Fig. 20 were obtained. This indicates a reduction which while being appreciable (7 decibels at 200-400 c.p.s. at $M=0{\cdot}99$), is probably insufficient to justify the introduction of such a unit. Two reasons may be put forward to explain the poor reduction compared with the peripheral spreader. The chief reason arises from the fact that the frequency is raised in the ratio d/w where w is the width of the spread jet and d the initial diameter. Thus for the two cases referred to here the frequency was raised in the ratio 12:1 by the peripheral unit as opposed to under 4:1 on the fishtail. Thus the sound was raised by over 3 octaves in the former, and slightly under 2 octaves in the latter case. Even so, the results in Fig. 20 indicate only a single octave increase. The answer lies in the increase in turbulence and the bad flow generally which occurs when a quick change is made in duct shape. In trying to improve the flat distribution, various devices such as turning vanes have been used. The gain obtained so far from any such arrangement has been small owing to the increased turbulence arising from them.

It is not suggested that an efficient fishtail cannot be designed; if a unit of sufficient length is used and a very long slit nozzle incorporated, a good sound suppressor should result. Gauzes and other devices designed to put in a pressure gradient will help although their introduction will undoubtedly eliminate the non-burning advantages of the fishtail compared with the peripheral spreader.

10. Discussion and Conclusion

The use of a device of this sort will raise the frequency of the peak noise to a value which is easier to attenuate than with existing circular jets, the frequency to which this peak may be raised depending only on practical circumstances of the thinness and length of the slit nozzle that can be achieved. The tests described in this paper have been carried out with very modest spreader ratios and a greater spread is advisable in actual installations. Furthermore any other means of suppression at the designer's disposal should be added to the system. For instance, a properly designed corrugated edge[4] should be incorporated, the width and depths of the corrugations being "tuned" to silence the peak noise otherwise obtained. Sound-proofing material can also be added around both the "trumpet" intake and around the annular nozzle. A ground muffler of

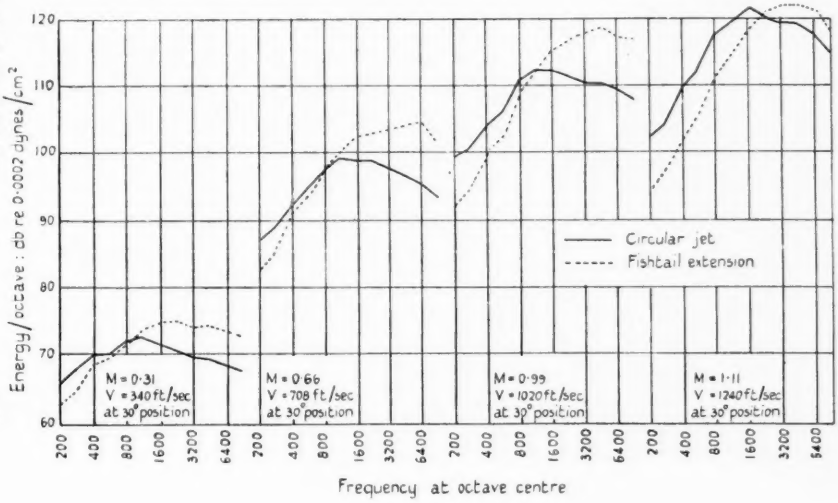


FIGURE 20. Comparison of spectra from jet and fishtail extension at various exit velocities.

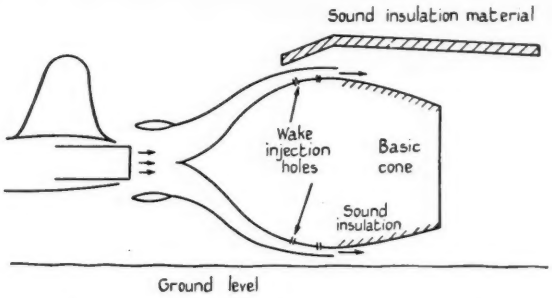


FIGURE 21. Ground muffler incorporating spreader (diagrammatic).

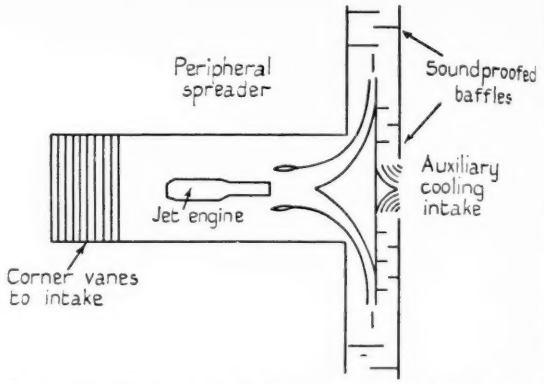


FIGURE 22. Engine test cell incorporating peripheral spreader.

this type is shown in Fig. 21 while an engine test cell incorporating the concept is shown in Fig. 22. Water injection can also be added very effectively especially as the slit nozzle provides an efficient method of introducing the water mass uniformly throughout the jet. With these additions used in a knowledgeable manner, it may well be claimed that the concept put forward in this paper can affect materially the problem of test cell and muffler design.

In stating these possible developments, it is well to point out that the additive principle of sound suppression does not always apply. For instance if the jet already has a corrugated flight nozzle, as may well be the practice, the noise suppression to be obtained with a spreader is possibly nearer that calculated from a frequency increase to a normal circular jet and not a corrugated one. A full-scale peripheral suppressor is now being built which will establish this point more clearly.

ACKNOWLEDGMENTS

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TECHNICAL NOTES

A Note on the Mixing Process in the Flow Induced by a High Velocity Air Jet

by

J. BLACK, Ph.D.

(Department of Aeronautical Engineering, University of Bristol)

IT IS WELL KNOWN that when a plane air jet of high velocity blows over a convex surface, such as the upper surface of a lowered trailing edge flap, it flows along the surface, remaining attached for a considerable length; in the case of the flap, it adheres right to the trailing edge. This effect, usually described as the Coanda effect, has been utilised in the attempts to increase lift at constant incidence by "flap-blowing"[1, 2, 3] in which the high velocity air jet is ejected either through slots in the flap shroud, or tangentially out of the flap surface.

The low velocity air stream approaching the flap over the wing upper surface, which in the absence of "blowing" would tend to separate at the flap shroud, is entrained by the high velocity jet, and the incipient flow separation over the flap thereby suppressed. The energy contained in the "blowing" jet can, in addition, also produce "super-circulation."

The generation of lift independently of incidence with a "jet flap" similarly depends on the entrainment of the main stream of fluid from right round the trailing edge by the high velocity jet emerging from the lower surface. The shrouded jet flap described by Davidson[4] is effectively a combination of both systems.

Davidson indicated in the same paper that in the mixing process the entrainment involved considerable "over-turning" of the main flow over the aerofoil, and suggested that because of the local acceleration in the vicinity of the trailing edge a suction drag on the profile is produced. Stratford in his related papers[5] analysed the mixing process on momentum principles, and also considered the "sink" effect of a jet in absorbing an external stream. He stressed that because the surrounding air must have a velocity component perpendicular to the jet in order to mix with it, his basic analysis, which assumed that jet and main stream velocities were locally parallel, could not take account of "secondary" losses. These losses he attributed to the fact that the entrained air was travelling locally in a different direction from that of the jet with which it was mixing. He reported an angle of 120° between a jet and the entrained flow.

Investigations of the entrainment process with flap blowing[6, 7] have revealed a similar "over-turning" or "sink" effect to that first described on the jet flap. In this case it is located in the immediate vicinity of the blowing slot in the shroud and extends along the flap chord.

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TEST RESULTS ON A FLAP DEFLECTED 60°

The simulated flap model, shown in Fig. 1, mounted between glass walls, was exposed to an air stream of 150 ft./sec. The schlieren photograph (Fig. 2), one of a series obtained in the tests by Earnshaw, Griffiths and Jones[6] shows clearly that the high velocity jet emerging from the shroud slot follows the flap contour, and projects beyond the "trailing edge."

The entrainment of the air stream flowing over the model was easily confirmed by hand, as the whole stream turned through 60° when the blowing air was released. Exploratory Pitot and yawmeter traverses to establish the extent of the mixing zone at the outer boundary of this jet, and the entrained air, were unsatisfactory, and a liquid-film technique was resorted to by Eyles and Foster[7]. A vertical dividing plate of black plastic cut to fit the model and coated with a suspension of titanium oxide in paraffin was used.

They found that the low velocity air stream had little effect on the liquid film, but when the blowing air was turned on, the high velocity jet immediately made a trace on the liquid film, which closely resembled its image in the schlieren picture (Fig. 3). Simultaneously, a strong circular motion of the liquid film was observed in the neighbourhood of the slot, and extending some way along the flap chord.

The liquid film was drawn in almost *normal* to the high velocity jet, the flow resembling that into a "sink"; where it met the jet, it turned abruptly to flow parallel to it. From there it flowed in with the main body of the low velocity air, which had been drawn round from beyond the region of highly curved flow.

To confirm that this "over-turning" effect was not due to the presence of the dividing-plate, or arose because of boundary layer effects on the plate and liquid film itself, smoke was released into the low velocity air stream upstream of the slot, with the plate removed. The strong attraction of the flow towards the flap surface is even more striking in the smoke photograph (Fig. 4). It was found that smoke released *downstream* of the flap at quite considerable distances was drawn radially inwards towards the slot region.

This flow suggested the existence of large negative pressure gradients, and preliminary pressure distribution tests have shown negative pressure coefficients of up to 10 (based on the low velocity stream) close to the slot on the surface of the flap. These large suctions are presumably the same as those mentioned by Stratford occurring over the hinge of a shrouded jet flap.

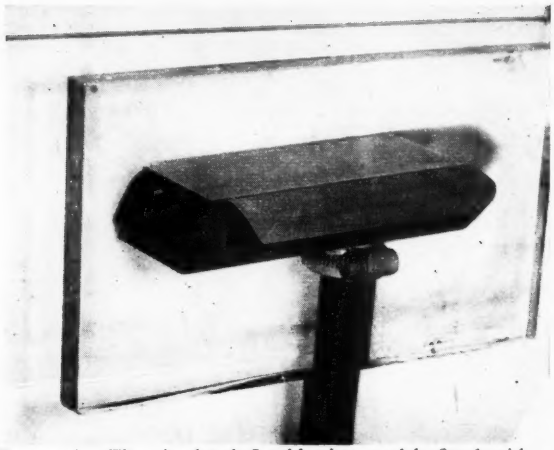

FIGURE 1. The simulated flap-blowing model, fitted with a 60° deflected surface block.

FIGURE 2. Schlieren photograph of the high-velocity jet blowing out of the slot.

FIGURE 4. Smoke released into the low-velocity air stream passing over the model is "attracted" inwards past the slot.

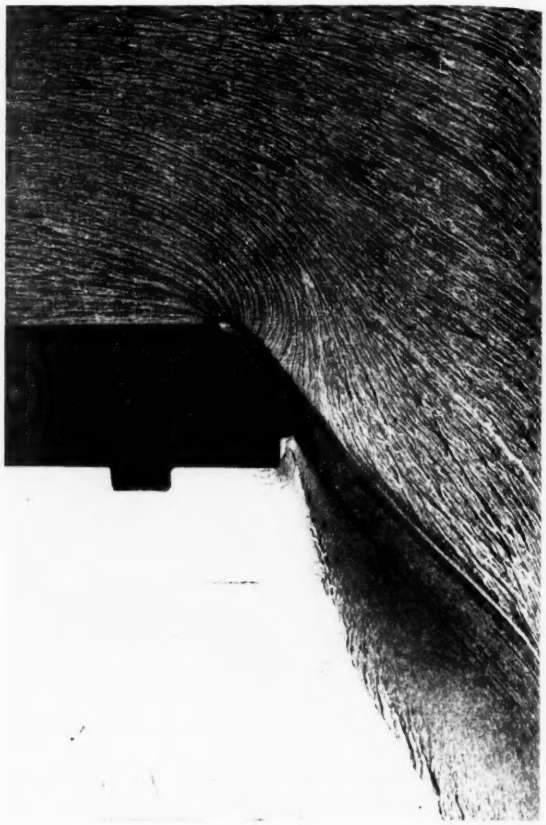

FIGURE 3. Liquid-film pattern of the air flow induced by a high-velocity air jet emerging from a "shroud" slot.

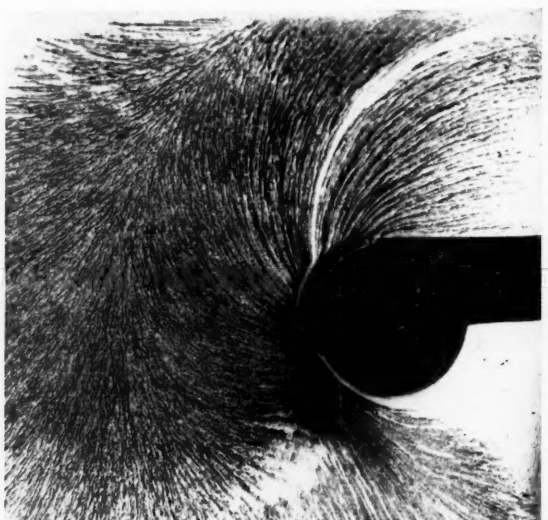

FIGURE 6. The high-velocity air remains attached to the cylinder surface through 170°. The "over-turning" of the induced flow is marked over almost the whole of this angle.

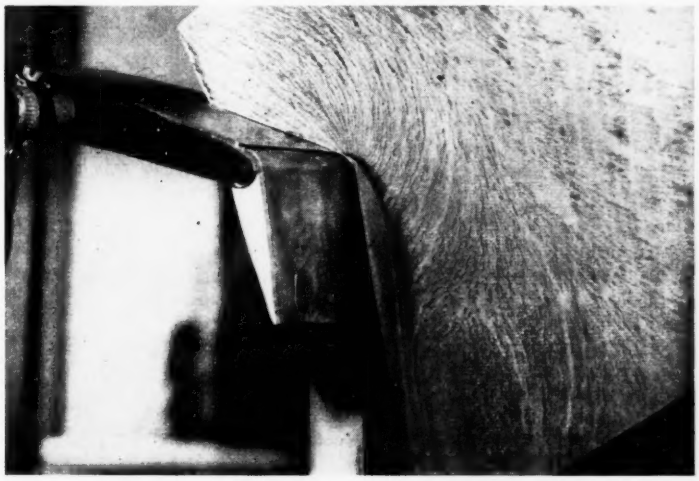

FIGURE 5. Liquid film pattern with a 60° deflected flap on an aerofoil at incidence with no end plates.

As a check that the phenomenon was not peculiar to the flap-simulation model, an aerofoil model with hinged flap, and shroud-blowing slot, also mounted between end-plates, was tested at incidence. The curvature effect was even more marked with this model (Fig. 5), where it can be seen to extend over the whole flap chord. The flow behaviour was unaffected when the end-plates were removed, except at the model tips, as would be expected.

INDUCED FLOW ROUND A CYLINDER

When the flap model is replaced by a cylinder[7] the flow pattern becomes very complex, as can be seen in the liquid film pattern in Fig. 6. The high velocity jet remains attached to the cylinder surface through almost 180° and the highly curved low-velocity flow "overturning" into the region of large suction is clearly defined. Various regimes of flow have been found, depending on blowing pressure, in which the induced air can either be separated from the high velocity jet, or can remain partly or fully attached. In all cases, however, the initial "overturning" is always present.

Large suctions, which would produce an appreciable drag, have been measured over almost the whole rear surface of the cylinder. Davidson suggested that the magnitude of the jet drag with a jet flap would depend on the strength of the entrainment effect, and so upon the shear velocity between the jet and main stream. He also expected that the jet drag would increase rapidly with jet deflection angle. No drag measurements have yet been made with this cylinder model, but the integrated pressure distributions indicate confirmation of Davidson's predictions.

THE INDUCTION EFFECT

It appears, therefore, that the entrainment of a low velocity air stream by a high velocity jet blowing over a convex surface does not arise from tangential inter-mixing at the jet-air stream interface, but involves two distant flow processes:—

1. The high velocity air jet follows the convex surface up to very large angles of deflection because of the Coanda effect.
2. As the jet flows along the convex surface, large negative pressures are produced, which "attract" the low-velocity air stream and cause it to flow inwards towards the surface. In the mixing region near the slot, the low-velocity air stream flows almost normal to the high velocity jet, in a similar manner to that first suggested by Davidson and Stratford in the case of the jet flap.

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*Reports submitted in part fulfilment of the requirements for the Degree of B.Sc. with Honours in the University of Bristol.

A Tension Field Calculator

by

K. G. F. NOBLE, Grad.R.Ae.S.

(*Stress Office, Handley Page Ltd.*)

PURPOSE OF THE CALCULATOR

The calculator is a device in slide rule form for assisting in the design and stressing of flat rectangular panels in shear.

In the Incomplete Tension Field theory, the ratio q/q_b becomes an important factor, where

q applied shear stress (lb./in.^{2})

q_b shear stress at which panel first buckles (lb./in.^{2}).

This ratio is normally evaluated by use of the formula

$$q_b = KE\,(t/b)^2$$

where E Young's modulus (lb./in.^{2})

t thickness of panel (in.)

a length of longer side of panel (in.)

b length of shorter side of panel (in.)

and K depends on the value of b/a and the edge conditions, and is normally obtained from R.Ae.S. Data Sheet 02.03.01.

This method becomes laborious when dealing with large numbers of panels.

By the use of the Calculator, q/q_b may be found quickly, with no unnecessary paper work.

DESIGN OF THE CALCULATOR

Edge conditions of idealised panels may be stated thus:

(*i*) All sides fixed.

(*ii*) Long sides fixed, short sides simply-supported.

(*iii*) Long sides simply-supported, short sides fixed.

(*iv*) All sides simply-supported.

The calculator described here deals with types (*ii*) and (*iii*) only, as types (*i*) and (*iv*) are rarely encountered, and their inclusion would detract from the simplicity of the design. The value of E used is 10^7 lb./in.^{2}, since aluminium alloys are at present the most commonly used materials.

Thus we have

$$q_b = K\,(t/b)^2 \times 10^7 \text{ lb./in.}^2$$

so that logarithmic scales may be marked out for t and b to perform the division, and since K depends only on b/a for any given edge conditions, q_b may be read off opposite a scale of b/a.

Further, if we provide a logarithmic scale for q, we may perform the division q/q_b, and in reading this off also read values of functions which are dependent on it, such as:

n the tension field pull factor

$R/(qt)$ the web joint rivet loading factor ($I = \infty$)

$M/(qtb^2)$ the maximum flange bending moment factor

F/Q the flange end load factor.

SCALES

A is panel thickness, t, plotted logarithmically and marked in the S.W.G. for convenience, from 28 to 12 S.W.G.

B is the length of the shorter side, plotted logarithmically and catering for up to 10 in. panel.

C is the b/a scale for condition (*iii*) above.

D is as C, but for condition (*ii*).

E is the logarithmic q_b scale.

F is the applied shear stress, q, scale.

G is the q/q_b scale, together with functions of q/q_b.

For convenience, the scales for condition (*ii*) are carried on the back of the scales for condition (*iii*) on the top slide.

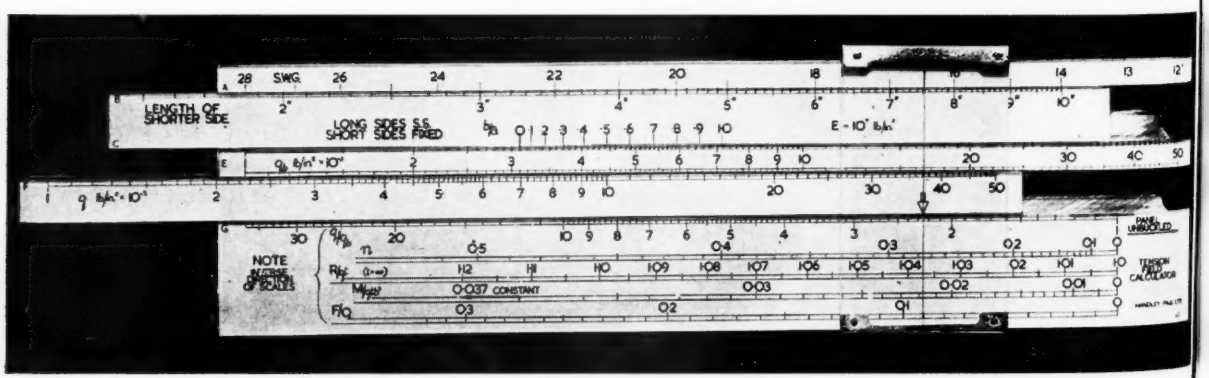
METHOD OF USE

When stressing a panel of fixed dimensions, first determine the edge conditions and select the appropriate side for the top slide. It will be noted here that in beam design, the stiffener pitch is usually less than the beam depth, giving rise to condition (*iii*) above, and consequent use of face "*BC*" on the top slide.

Move the cursor to the gauge of the panel on scale "*A*." Then move the top slide until the shorter side of the panel on scale "*B*" is under the cursor line.

Determine the "b/a" ratio of the panel, and move the cursor to this value on scale "*C*" or "*D*." The buckling stress, q_b, now lies under the cursor line on scale "*E*."

Received 23rd July 1957.



Determine the applied shear stress, "q," and move the lower slide until this value appears under the cursor line on scale "F."

Now move the cursor to the arrow on the lower slide and q/q_b will lie under the cursor on scale "G," together with its associated functions.

When designing panels, the reverse procedure may be adopted, starting with a sensible value for q/q_b, and first guessing the panel thickness to obtain a reasonable value for q, and working to obtain the same value for thickness on scale "A."

EXAMPLE

The photograph shows the calculator set for a panel having dimensions 6 in. × 12 in. × 18 S.W.G., with long sides simply-supported, short sides fixed. Since $b/a=0{\cdot}5$, we have $q_b=4{,}450$ lb./in.^{2}, and if the applied shear stress is 10,000 lb./in.^{2} we have $q/q_b=2{\cdot}25$ lying under the cursor line, together with:

$$n=0{\cdot}275$$
$$R/(qt)\,(I=\infty)=1{\cdot}037$$
$$M/(qtb^2)=0{\cdot}0218$$
$$F/Q=0{\cdot}09$$

DEVELOPMENT

A scale is being devised so that $R/(qt)$ may be obtained for any value of $I/(b^3t)$, since the present $R/(qt)$ scale gives the rivet loading only where the "I" of the flange may be considered infinite.

A further scale to be added will give permissible shear stresses for permanent deformation and failure of the panel in shear.

ACKNOWLEDGMENT

The author wishes to thank F. Tyson for his suggestions and encouragement, and Handley Page Ltd. for permission to publish this note.

Spiral and Elliptical Orbits

A number of comments have been received on the Technical Note by Rear-Admiral Brian Egerton, R.N.(Retd.), which was published in the June 1957 JOURNAL *(pp.* 422 *and* 423). *As many of them dealt with similar points, only a selection has been printed. In one or two cases Rear-Admiral Egerton has replied separately. In addition to those published below, comments have been received from: J. W. Bradly, B.Sc., Stud.R.Ae.S., and C. Wilson, B.Sc., Stud.R.Ae.S.; E. C. Capey; R. A. Gellatly, B.Sc., Grad.R.Ae.S., and K. E. Baker, B.Sc.; W. G. Gilchrist (R.A.F.); B. A. Hunn, B.Sc., Comp.R.Ae.S.; W. B. Klemperer; R. C. Lock; J. R. Palmer, M.A., A.F.R.Ae.S.; C. G. Paradine; Lieut. P. C. Parks, B.A., Grad.R.Ae.S., R.N.V.R.; R. H. Peacock, M.Sc., A.F.R.Ae.S.; G. B. Saksena, M.Sc., A.F.I.A.S., A.F.R.Ae.S.; J. Snell, B.Sc., Grad.R.Ae.S.; Professor J. Lockwood Taylor, D.Sc., A.F.R.Ae.S.; J. D. Teare, M.A., Grad.R.Ae.S.; R. I. Vaughan, M.A., Grad.R.Ae.S.; H. M. Yeatman, M.A., A.F.R.Ae.S.*

E. F. RELF, C.B.E., F.R.S., F.R.Ae.S.

Rear-Admiral Egerton's mistake is to assume (para. 8) that, because $\frac{d^2r}{dt^2}$ is not zero, the path is "some sort of spiral." He is evidently thinking as though a radial acceleration of constant magnitude were imposed on a circular motion. But $\frac{d^2r}{dt^2}$ never *is* zero in any orbit except a circular one, or at two points in an elliptic one.

There is no doubt of the mathematics involved in central orbit theory and the motion is always a conic if the central acceleration varies inversely as r^2. If a satellite is started at just the right circumferential velocity it will, as is stated, describe a circle. If sent off faster or slower it will describe an ellipse and return to the same point (in absence of air friction) going respectively farther from and nearer to the centre on the opposite side of the earth, *unless* the velocity is more than $\sqrt{2}\times$ the circular orbital velocity, *i.e.* greater than the so-called escape velocity, when the satellite will never return.

(The general equation of motion is

$$\frac{d^2u}{d\theta^2}+u=\frac{P}{h^2u^2}$$

where $u=\frac{1}{r}$, P is the acceleration towards the centre (a function of r) and $h=r^2\frac{d\theta}{dt}$, a constant in the absence of acceleration normal to the radius vector.)

W. E. HICK, M.A., M.D., Comp.R.Ae.S.
(*Cambridge*)

The principal interest of Rear-Admiral Egerton's Note is as a reminder that Newtonian Mechanics, being time-reversible, cannot admit an irreversible process such as the asymptotic spiral which he derives. A satellite started at radius r, with mass m, zero radial velocity and a tangential velocity of $v=\omega r$ has, in Egerton's notation, a total energy of $m\mu/r^2+\frac{1}{2}mr^2\omega^2=m(\mu+\frac{1}{2}\lambda^2)/r^2$. This, of course, decreases with increasing r. So if the initial velocity, *i.e.* kinetic energy, is too large for equilibrium at

radius r, the satellite, although it will certainly begin to move outwards, will not find a larger *circular* orbit which will enable it to balance its energy budget; it must choose one of the other conic sections, such as the ellipse.

Rear-Admiral Egerton's paradox, in fact, relies, as all paradoxes do, on smuggling in something which is logical in itself, but happens to contradict the premises. His exponential spiral (innumerable other functions are possible) is simply a device for getting rid of the surplus energy—when the physical assumptions do not allow it to be got rid of!

PETER FARR, B.Sc.(Eng.), A.F.R.Ae.S.
(Dowty Mining Equipment Ltd.)

Rear-Admiral Egerton's Note is of special interest to those who may have been speculating on the difficulties of launching an artificial earth satellite into free orbit.

Such an orbit would have to be outside the earth's atmosphere, so that air resistance will be negligible; for simplicity the influence of heavenly bodies other than the earth may be neglected.

Application of the classic theory of motion of a particle under the influence of a force directed to a fixed point and varying inversely with the square of the distance from this point will readily show that an elliptic or parabolic path is obtained.

It should be pointed out that this theory has successfully explained all known planetary motions, and further where differences between theoretical and observed paths have been found, these have been shown to be due to presence of hitherto unknown planets which were subsequently discovered (*i.e.* Neptune and Pluto).

Because of this, the idea of spiral paths must be viewed with profound suspicion, and indeed there does not appear to be any justification for such an idea in the analysis presented.

With the previous notation, consider the equation:

$$\frac{d^2r}{dt^2} = -\frac{\mu}{r^2} + \frac{\lambda^2}{r^3}$$

this shows the radial acceleration to be positive for values of $r < \frac{\lambda^2}{\mu}$ and negative (inward) for values $> \frac{\lambda^2}{\mu}$. Further the radial velocity will therefore be a maximum in either direction when $r = \frac{\lambda^2}{\mu}$. This must indicate a motion oscillatory in character relative to the circle $r = \frac{\lambda^2}{\mu}$, and not a spiral towards it. The spiral path quoted gives $-\frac{d^2r}{dt^2} = -\frac{\mu}{r^2} + \frac{\lambda^2}{r^3}$ which is quite different from the condition actually prevailing, as it refers to a repulsion from the circle $r = \frac{\lambda^2}{\mu}$. Thus it may be accepted that the well known solution applies.

What is not immediately apparent, however, is whether such a satellite can be placed in an orbit which will be clear of the earth's atmosphere at all points, or indeed, the earth's surface!

A three-stage rocket of the type now being built will only just be capable of reaching the required speed and altitude, and the mechanism for placing the satellite on the correct path at the correct speed may be subject to dangerous inaccuracies.

These inaccuracies are typical of mechanisms which determine the velocity, height, and direction at any time by one or two integrations of the relevant acceleration from take-off, because such methods lead to cumulative errors.

Accepting the presence of inaccuracies, the system must be designed to be capable of attaining a minimum concentric orbit radius b say from the earth's centre, at velocity $u = \sqrt{\frac{\mu}{b}}$.

In general, therefore, at the "burn-out" point the satellite will be at velocity nu, height mb, and on a path inclined α to the horizontal. The constants n and m are slightly greater than unity and represent the cumulative computing errors, and α is a small angle arising from the same cause. In this case the satellite will have a higher angular momentum than that required for the minimum concentric orbit. The concentric orbit of the same λ now has a radius $c = n^2m^2b$ and velocity $v = u/(nm)$.

The radial velocity of the satellite in crossing this orbit will be greater than $u\alpha$ and may be determined as follows:

$$\frac{d^2r}{dt^2} = \frac{dr}{dt} \cdot \frac{d}{dr}\left(\frac{dr}{dt}\right) = -\frac{\mu}{r^2} + \frac{\lambda^2}{r^3} = -\frac{u^2b}{r^2} + \frac{n^2m^2u^2b^2}{r^3}$$

integrating with respect to r

$$\frac{1}{2}\left(\frac{dr}{dt}\right)^2 = \frac{ub}{r} - \frac{n^2m^2u^2b^2}{2r^2} + \text{constant}$$

since $\frac{dr}{dt} = nu\alpha$ when $r = mb$

$$\text{constant} = \frac{n^2u^2\alpha^2}{2} - \frac{u^2}{m} + \frac{n^2u^2}{2}$$

if the radial velocity is $v\beta$ when $r = c = n^2m^2b$ then

$$v\beta = nu\left[\alpha^2 + \left(1 - \frac{1}{n^2m}\right)^2\right]^{\frac{1}{2}}.$$

Considering now x as a small radial difference between the actual and concentric orbits,

$$\frac{d^2r}{dt^2} = -\frac{u^2b}{(n^2m^2b + x)^2} + \frac{n\,m\,u\,b}{(n^2m^2b + x)^3}$$

$$\simeq -\frac{u^2}{n^4m^4b}\left(1 - \frac{2x}{n^2m^2b} - 1 + \frac{3x}{n^2m^2b}\right)$$

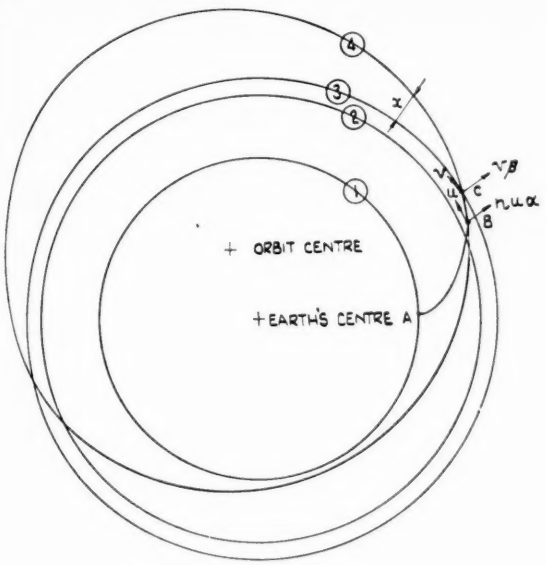
$$\simeq -\frac{u^2x}{n^6m^6b^2}, \text{ } i.e. \text{ simple harmonic motion.}$$

The maximum value of x, $\delta = \frac{v\beta n^3m^3b}{u}$

Therefore $\delta = n^4m^3b\left[\alpha^2 + \left(1 - \frac{1}{n^2m}\right)^2\right]^{\frac{1}{2}}$

the periodic time, $T = 2\pi\frac{n^3m^3b}{u}$.

Since this is also the time for one revolution on the concentric orbit of the same λ, the actual orbit will approximate closely to an eccentric circular orbit radius c and eccentricity δ (*see* Fig. 1).



(1) Earth's surface radius **a**.
(2) Projected orbit radius **b**.
(3) Actual equivalent orbit radius **c**.
(4) Actual eccentric orbit radius **c**.

A = Launching point.
B = Burn out point.
C = Intersection point actual orbit and equivalent circular orbit.

FIGURE 1.

This orbit will be followed continuously from the instant of burn-out, provided the initial assumptions hold.

To establish the allowable errors in computation the eccentricity, δ, must be expressed as a fraction of the height of the concentric orbit.

This height is $(n^2m^2b - a) = Z$; putting $b = ha$ and $N = \frac{\delta}{Z}$

$$N = \left(\frac{n^4m^3h}{n^2m^2h - 1}\right)\left[\alpha^2 + \left(1 - \frac{1}{n^2m}\right)^2\right]^{\frac{1}{2}}$$

since $\frac{\partial N}{\partial \alpha}$ is positive; $\frac{\partial N}{\partial n}$ is negative

$\frac{\partial N}{\partial h}$ is negative; $\frac{\partial N}{\partial m}$ is negative.

The allowable error will be least when n, and $m = 1{\cdot}00$ and h is a minimum.

Thus, taking the earth's radius as 3,950 miles, the concentric orbital height as 300 miles minimum, the atmospheric height as 100 miles, the results obtained are shown in Table I.

TABLE I

N	$\alpha°$	*Height (miles)*	
		Maximum	*Minimum*
0	0	300	300
0·33	1·33	400	200
0·67	2·67	500	100
1·00	4·00	600	0

At $\alpha = 1{\cdot}33°$ a safe path is obtained, and this may be taken as the maximum allowable error. At $\alpha = 2{\cdot}67°$, the earth's atmosphere is touched, which will lead to a quick descent.

At $\alpha = 4°$ the satellite would certainly strike the earth on the first revolution.

Since 300 miles minimum probably represents the best concentric orbit which can be obtained under present conditions, and an error of 2° or 3° in turning through 90° is not outside the realm of possibility, there is concluded to be an appreciable risk of failure to obtain free orbit.

The foregoing calculations are admittedly inaccurate inasmuch as 300 miles is not really small in comparison with 4,250 miles. However, there is sufficient accuracy to justify the above conclusion.

Thus where the power available is insufficient to allow a concentric free orbit of radius greater than say 1·2 times the radius of the earth, it might be wiser to await the arrival of a more powerful engine.

D. S. WOODWARD, Stud.R.Ae.S.,

and G. E. DAVIES, Stud.R.Ae.S.
(*de Havilland Aircraft Co. Ltd.*)

IN Rear-Admiral Egerton's Note there appear to be three statements which are at variance with his conclusions.

(1) In Part 8 he states

$$\frac{d^2r}{dt^2} = \frac{-\mu r + \lambda^2}{r^3} \text{ where } \mu = MG,$$

where $\frac{d^2r}{dt}$ is not generally $= 0$, and the normal path is some sort of *spiral* (?). In fact it is an ellipse as will be shown below.

(2) He also states that the distance r will increase from r_0, with decreasing acceleration, to a final value r_t (in infinite time) (?).

To achieve this condition, since there is no radial velocity at the launch, $\frac{d^2r}{dt^2}$ must start positive and then tend to zero asymptotically from the negative side. If $\frac{d^2r}{dt^2}$ is plotted against r it will be seen that this does happen, BUT NOT UNTIL $r \longrightarrow \infty$. (*See* graph).

Since $\omega r^2 = \lambda$, when $r = \infty$, $\omega = 0$ and the satellite has no orbit round the earth.

(3) Having assumed that $\frac{r_t}{r} = 1 + be^{-\theta}$

where $r_t = \frac{\lambda^2}{\mu}$ and b is a constant, he produced

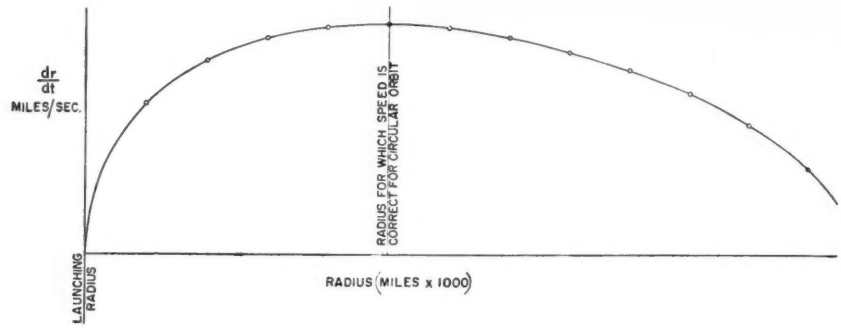


FIGURE 1 (*left*). Radial velocity ~ radius.

$$\frac{dr}{dt} = \frac{\lambda b}{r_1} e^{-\theta} = \frac{b\mu}{\lambda} \text{ when } \theta = 0,$$

i.e. when the satellite is launched it has a constant radial velocity, yet the initial conditions stated that:—

$$u_0 = \frac{dr}{dt} = 0.$$

The Equation of the Orbit

Assuming $$\frac{d^2r}{dt^2} = -\frac{\mu}{r^2} + \frac{\lambda^2}{r^3} \neq 0$$

and $$\frac{dr}{dt} \neq 0,$$

except when $\theta = t = 0$ and $r = r_0$.

Then putting $u = \frac{dr}{dt}$,

$$\frac{d^2r}{dt^2} = \frac{du}{dt} = \frac{du}{dr}\frac{dr}{dt} = u\frac{du}{dr}$$

i.e. $$u\frac{du}{dr} = -\frac{\mu}{r^2} + \frac{\lambda^2}{r^3}.$$

Therefore $$\frac{u^2}{2} = \frac{\mu}{r} - \frac{\lambda^2}{2r^2} + K \quad . \quad . \quad . \quad (1)$$

where $K = -\frac{\mu}{r_0} + \frac{\lambda^2}{2r_0^2}$ since $u = 0$ when $r = r_0$.

Now $$u = \frac{dr}{dt} = \frac{dr}{d\theta}\frac{d\theta}{dt} = \frac{\lambda}{r^2}\frac{dr}{d\theta}.$$

Therefore substituting in (1)

$$\frac{\lambda}{r^2}\frac{dr}{d\theta} = \sqrt{\left\{\frac{2\mu}{r} - \frac{\lambda^2}{r^2} + 2K\right\}}$$

i.e. $$\theta = \int \frac{dr}{r\sqrt{\left\{\frac{2\mu}{\lambda^2}r - 1 + \frac{2K}{\lambda^2}r^2\right\}}}$$

Putting $$r = \frac{1}{y}$$

i.e. $$dr = -\frac{1}{y^2}dy$$

$$\theta = \int \frac{-dy}{\sqrt{\left\{\frac{2\mu}{\lambda^2}y - y^2 + \frac{2K}{\lambda^2}\right\}}}$$

i.e. $$\theta = \int \frac{-dy}{\sqrt{\left\{\frac{2K}{\lambda^2} + \frac{\mu^2}{\lambda^4} - \left(y - \frac{\mu}{\lambda^2}\right)^2\right\}}}$$

Therefore $$(\theta + \alpha) = \cos^{-1}\frac{\left(y - \frac{\mu}{\lambda^2}\right)}{\sqrt{\left\{\frac{2K}{\lambda^2} + \frac{\mu^2}{\lambda^4}\right\}}}$$

i.e. $$\cos(\theta + \alpha) = \frac{\left(\frac{\lambda^2}{r} - \mu\right)}{\sqrt{(2K\lambda^2 + \mu^2)}}$$

Therefore

$$\frac{\lambda^2}{\mu r} = 1 + \sqrt{\left\{\frac{2K\lambda^2}{\mu^2} + 1\right\}}\cos(\theta + \alpha)$$

$$= 1 + \sqrt{\left\{\frac{2\lambda^2}{\mu^2}\left(\frac{-\mu}{r_0} + \frac{\lambda^2}{2r_0^2}\right) + 1\right\}}\cos(\theta + \alpha)$$

$$= 1 + \frac{1}{r_0}\left(\frac{\lambda^2}{\mu} - r_0\right)\cos(\theta + \alpha)$$

Now when $\theta = 0$, $r = r_0$

Therefore $$\frac{\lambda^2}{\mu r_0} = 1 + \frac{1}{r_0}\left(\frac{\lambda^2 - \mu r_0}{\mu}\right)\cos\alpha.$$

Therefore $$\cos\alpha = \frac{\lambda^2 - \mu r_0}{\mu r_0} \cdot \frac{\mu r_0}{\lambda^2 - \mu r_0} = 1.$$

i.e. $$\alpha = 2n\pi$$

Thus the orbit of the satellite may be written:—

$$\frac{\lambda^2}{\mu r} = 1 + \left(\frac{\lambda^2 - \mu r_0}{\mu r_0}\right)\cos(\theta + 2n\pi)$$

which is the polar form of an ellipse (if $\lambda^2 - \mu r_0 < \mu r_0$)

$$\frac{l}{r} = 1 + e\cos\theta$$

where l = semi-latus-rectum $= \frac{\lambda^2}{\mu}$

and e = eccentricity $= \frac{\lambda^2 - \mu r_0}{\mu r_0}$.

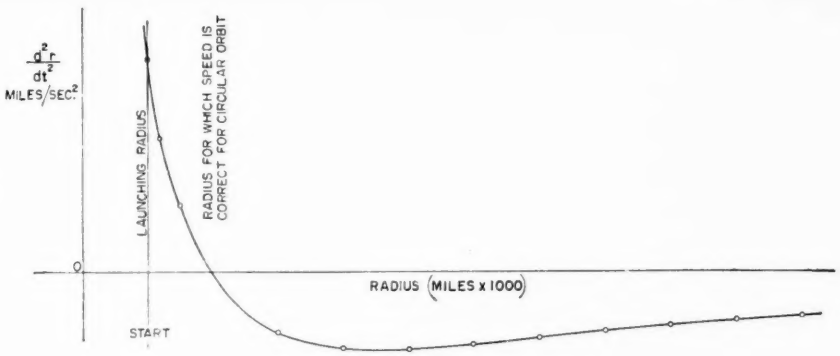


FIGURE 2 (*right*). $d^2r/dt^2 \sim r$ for a satellite launched in excess of circular orbit speed.

It is interesting to note that if $\lambda^2 - \mu r_0 = \mu r_0$ then the satellite will escape along a parabolic path and if $\lambda^2 - \mu r_0 > \mu r_0$ then the escape path will be a hyperbola. If $\lambda^2 = \mu r_0$ then the eccentricity is zero and the orbit is circular and $r_0 = \dfrac{\lambda^2}{\mu}$ as obtained by Rear-Admiral Egerton.

If the satellite is launched with a radial velocity this will add a term $\dfrac{U_0^2}{2}$ to K and change the eccentricity of the orbit and will also add a phase angle ϕ such that $\alpha = \phi + 2n\pi$.

A. E. CAUSON

The arguments offered in Rear-Admiral Egerton's Technical Note on Orbits suffers the defect common to some engineers of not trusting the mathematics and yet wishing to use it somehow in order to "prove" something. They have an eternal question of whether or not to put in the Centrifugal force or the Coriolis force (and what signs?) when indeed these things do not exist in their own right being merely manifestations of the differential relationships of the co-ordinates used. For motion in a plane the radial and tangential components of acceleration per unit mass are shown to be

$$\frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dr}\right)^2 \text{ and } \frac{1}{r}\frac{d}{dt}\left(r^2\frac{d\theta}{dt}\right)$$

and if the mass is constant Newton's second law permits these to be equated to the forces per unit mass in the directions of r and θ increasing. With gravitational problems there is no tangential force and hence

$$r^2\frac{d\theta}{dt} = \text{constant} = \lambda^2.$$

Albeit both methods arrive at the expression given in point (8) and at this stage the much despised text books usually change the variables to yield the equation of the path and possibly appear to disguise the $1/r^3$ term. However, on integrating the (r, t) equation, as below, r does not approach an asymptotic value. For indeed in general, why should dr/dt (the radial velocity)$\longrightarrow 0$ when d^2r/dt^2 (the radial acceleration)$\longrightarrow 0$ without its changing sign.

Using the non-mathematical parlance it is a matter of common experience that when a body ceases to accelerate it has to decelerate before it stops.

Now $$\frac{d^2r}{dt^2} = -\frac{\mu_r - \lambda^2}{r^3}.$$

Multiply both sides by $2\,dr/dt$ and integrate.

Therefore $$\left(\frac{dr}{dt}\right)^2 = \frac{2\mu}{r} - \frac{\lambda^2}{r^2} + C \quad [C \text{ is a constant}].$$

Initial conditions.

$$\frac{dr}{dt} = 0 \text{ when } r = r_0$$

and $$\omega = \omega_0 = \frac{v_0}{r_0} \textit{ i.e. } \lambda^2 = v_0 r_0$$

i.e. $$0 = \frac{2\mu}{r_0} - \frac{v_0 r_0}{r_0^2} + C$$

or $$C = \frac{v_0 - 2\mu}{r_0}.$$

Further apsidal distances, if any, are to be found when $(dr/dt)^2 = 0$, *i.e.* when

$$0 = \frac{2\mu}{r} - \frac{\lambda^2}{r_0^2} + C$$

or $$r = -\frac{\mu \pm \sqrt{(\mu^2 + \lambda^2 C)}}{C}$$

which reduces to

$$r = r_0 \text{ or } r = -\frac{v_0}{v_0 - 2\mu} r_0$$

and provided $v_0 > 2\mu$ these correspond to the extreme ends of the major axis of the ellipse.

Rear-Admiral Egerton's Reply

NOTATION

- r radius vector (always positive)
- u radial velocity
- v velocity at right angles to radius vector
- w velocity along the orbital curve
- θ angle measured from a convenient zero radius vector
- ω angular velocity of body about a centre

$\lambda = \omega r^2 =$ constant
M mass of central body
m mass of ship or other revolving body
$\mu = MG$
G gravitational constant
$r_t = \lambda^2/\mu$
$\rho = MG/r^2$
g earth's gravitational constant
s.l.r. semi-latus-rectum of an ellipse
b eccentricity of an ellipse

1. THE NUMBER of criticisms of my note in the June 1957 JOURNAL reassures me that the subject of Spiral and Elliptical Orbits is one fit for discussion.

Each of the criticisms is derived from the statement:— "Given the inverse square law of gravitation, every orbit in Nature is a conic section. From which it follows that no orbit involving a spiral, which is a-periodic, is possible in Nature."

I do not know who originated the "classic" theorem. It is not in Newton's *Principia*, yet all writers have reproduced the same theorem, and the statement is based upon it.

The theorem is discussed and analysed in Sections 7, 8 and 9 of my original note, and is not therefore discussed again here. For the text book discussion of the theorem see Loney's *Dynamics of a Particle* (1952), paras. 53 and 66 (or any similar text book if you prefer it).

2. The logical and natural way to study orbital motions is to consider some law and from it find the orbit. Of course one can start off with any orbit one likes and find the law which governs it.

Newton, on the strength of Kepler's observations, took the second method, *i.e.* given the orbit, what is the law? (*Principia*, Book I, prop. XI, problem VI). See also *Isaac Newton* by J. W. N. Sullivan, p. 69 (1938).

3. In what follows I am adopting the first method, *i.e.* considering some law and from it deducing the orbit. The law of gravitation is accepted as a *sine qua non* in anything said.

4. Consider the equation

$$\frac{d^2r}{dt^2} = -n^2\left(-\frac{\mu}{r^2} + \frac{\lambda^2}{r^3}\right)$$

where $n^2 = -1$ or $+1$. (Any other numerical values would not comply with the law of gravitation.)

The question is, what orbit does that equation determine?

Multiplying by $2dr/dt$ and integrating:—

$$\left(\frac{dr}{dt}\right)^2 = n^2\left(\frac{\lambda^2}{r^2} - \frac{2\mu}{r} + C\right)$$

One solution is obtained with $C = \frac{\mu^2}{\lambda^2}$: then

$$\frac{dr}{dt} = \pm n\left(\frac{\lambda}{r} - \frac{\mu}{\lambda}\right) \quad . \quad . \quad . \quad . \quad \text{(A)}$$

Setting

$$\frac{\lambda^2}{\mu r} - 1 = be^{-n\theta}$$

and differentiating,

$$-\frac{\lambda^2}{\mu r^2} \cdot \frac{dr}{dt} = -n\,(be^{-n\theta})\,\frac{d\theta}{dt}$$

or $$-\frac{\lambda}{\mu} \cdot \frac{dr}{dt} = -n\left(\frac{\lambda^2}{\mu r} - 1\right) \text{ since } \frac{d\theta}{dt} \cdot r^2 = \lambda$$

i.e. $$\frac{dr}{dt} = n\left(\frac{\lambda}{r} - \frac{\mu}{\lambda}\right) \quad . \quad . \quad . \quad . \quad \text{(B)}$$

(B) agrees with (A) whether $n = i$ or $n = 1$, but this is still not necessarily the *only* solution.

(In my note I said The equation instead of An equation. This was rightly dropped upon.)

When $n = 1$, the spiral case, the forces of Nature are not reversed as one critic suggests; the interpretation is that d^2r/dt^2 is in the direction of dr/dt *decreasing*, and it remains so as $e^{-\theta}$ approaches 0.

dr/dt is not 0 when $\theta = 0$ (as it is in the ellipse); it tends towards 0 as θ increases.

If a satellite in a circular orbit at a distance r_0 has *transverse* velocity v_0, and this is increased to v_1, the act of doing so imparts a radial velocity $u_0 = v_1 - \frac{\mu}{v_1 r_0}$ which may be likened to "skidding."

At 7,000 Km. and v_0 7·6 Km./sec., $u_0 = 0$ Km./sec.
At 7,000 Km. and v_1 7·0 Km./sec., $u_0 = -1{\cdot}1$ Km./sec.
At 7,000 Km. and v_1 8·0 Km./sec., $u_0 = +0{\cdot}9$ Km./sec.

The new orbit cannot *touch* the old one, but must cut it at an angle whose tangent is u_0/v_1.

It is now seen that the circle $r = r_t$ is the orbit to which the spirals with b positive and negative are asymptotic.

There is no indication that $n = i$ or $n = 1$ should have preference over the other; both comply with the law, and preserve constancy of angular momentum. $n^2 = -1$ gives an ellipse; $n = 1$ a spiral, and no other values of n satisfy the equation. The unique positive value $n = 1$ shows that the spiral very rapidly approaches the circle $r = r_t$.

$e^{-2\pi} = 0{\cdot}002$ (approximately), and $e^{-2q\pi} = (0{\cdot}002)^q$.

The planets have made many millions of revolutions, so that for them the distinction between the spiral and the circle is unobservable by present known methods. Nevertheless, the two curves are and always remain quite distinct and have distinct properties.

The distinction for the planets is important in relation to their past history and their origin, which could be in the Sun if their spirals are outward, or outer space if inward: and if orbits are spirals, each carries a "sense" of Past and Future, derived from gravitation.

The distinction would be of great importance in other gravitational systems, and if accepted might alter current views on the alleged "expanding universe" and even on radio activity which have exponential properties.

5. The new phenomenon soon to be observed is a body starting in a fresh orbit with $\theta = 0$.

What will it do in its *first* revolution?

Where will it be when $\theta = 2\pi$?

According to current theory it will return *exactly* to the point where it started, no matter what radial and transverse velocities it started with, provided only that it does not crash or escape altogether.

This seems to me to be quite incredible.

If my prediction is wrong, what will be the eccentricity of the orbit?

According to one authority, using my notation, the change of eccentricity when v, the transverse velocity, is altered, is $\delta b = \frac{\delta v}{v}\left(\frac{1-b^2}{b}\right)\frac{r_t v^2 - \mu}{\mu}$.

With $b = 0$ (for an initial circle), this looks like infinity, until we note that $r_t v^2 - \mu = 0$, when we get 0/0.

Does this mean that the satellite can choose *any* orbit? Another author, perhaps smelling a rat, ignores the question altogether. These are not rhetorical questions, but will soon call for definite answers.

Two printing errors in my original Note have been pointed out by W. B. Klemperer, they are:—

In lines 6, 7, 8, 9 and 10 of the last column of page 423 λ should be replaced by λ^2 and λ^2 by λ^4; also in the last equation e^{θ} should read $e^{i\theta}$.

6. *Referring to specific points*:—

E. F. RELF: I only consider the ellipse, and the spiral developed from a circle. In the spiral which I used, d^2r/dt^2 approaches zero as θ increases without limit. It is not constant. Its rate of change, d^3r/dt^3 is zero when dr/dt is zero, and, on the inward spiral, when

$$r=\frac{3}{2}\frac{\lambda^2}{\mu} \quad \text{or} \quad \frac{3}{2}r_f.$$

(*See* Reply to A. Causon).

DR. W. E. HICK: The doctrine of time reversibility *is derived* from the ellipse, and I would suggest that it should not be used to prove that spirals are impossible.

It would be of great interest to be told *which* ellipse would be chosen, if a circular orbit is inadmissible.

A. CAUSON: By working in terms of accelerations, no "eternal question" of forces is raised, and the matter of signs seems quite simple. It would have been possible to write my note without any mathematics, but the result would have been far from clear.

The layman, while trusting to mathematics, may sometimes doubt the postulates on which they are based or the conclusions if they seem to conflict with logic.

Initial conditions. These, in the case stated in my note, are the conditions which apply to a circular orbit *after* power has been applied to change λ.

dr/dt is not then 0 when $r=r_0$, neither is λ^2 equal to v_0r_0. Would not the general solution of the equation for $(dr/dt)^2$ show what values of C are possible?

Since

$$\pm\frac{d^2r}{dt^2}=-\frac{u}{r^2}+\frac{\lambda^2}{r^3}$$

$$\pm\frac{d^3r}{dt^3}=\left(\frac{2u}{r^3}-\frac{3\lambda^2}{r^4}\right)\frac{dr}{dt}$$

d^3r/dt^3 changes sign when $r=\dfrac{3\lambda^2}{2u}$ (which occurs on an inward spiral) and when $dr/dt=0$, *i.e.* $r=r_f$.

P. FARR: To a layman, the idea that a planet, which might be a light-year distant from its primary, after each revolution returns, not a few miles or a few inches from, but *exactly* to the point where it started seems extremely improbable. A spiral-near-ellipse explains *all observed* planetary motions and avoids the strain on his power of belief.

If I have understood the last part of his remarks, he uses an eccentric circle as an approximation to an ellipse. Would it not have been better to use an ellipse and state its eccentricity?

However that may be, there is evidence of the narrow limits permissible in the speed on shutting off to avoid disaster in the first revolution. In the case stated in my note if v on shutting off power were 7·2 instead of 7·5 km./sec. the satellite would be well in the danger zone in the first revolution.

D. S. WOODWARD AND G. E. DAVIES: This detailed criticism leads me to hope that the authors will undertake a general solution of the orbit derived from the equation:

$$\pm\frac{d^2r}{dt^2}=-\frac{\mu r+\lambda^2}{r^3}.$$

Referring to their remarks:—

(1) $\dfrac{d^2r}{dt^2}$ is the *net* acceleration. In the ellipse it is proportional to cos θ, and its mean value is 0 (when $\mu r=\lambda^2$). It is periodic about that value.

In the spiral, it is not $=0$, but tends towards that value as θ increases. The demonstration that the path cannot be spiral is based on initial conditions that can only give an ellipse.

(2) There is no radial velocity if the satellite is launched in a circular orbit with transverse velocity exactly right for that orbit:— $v_0=\sqrt{\left(\dfrac{\mu}{r}\right)}$.

But if it is launched (as in my note) with a transverse velocity greater than v_0, it starts with a *radial* velocity outwards (+):

$$\frac{r_f}{r}-1=be^{-b} \quad ; \quad r_0=\frac{r_f}{1+b} \text{ when } \theta=0$$

$$\frac{dr}{dt}=\frac{\lambda}{r_f}\cdot be^{-\theta} \; ; \; \frac{dr}{dt}=u_0=\frac{\lambda b}{r_f} \text{ when } \theta=0 \text{ (outwards).}$$

$$\frac{d^2r}{dt^2}=-\frac{\lambda}{r_f}\cdot be^{-\theta}\cdot\frac{d\theta}{dt}=-\frac{\lambda^2}{r_fr^2}\cdot be^{-\theta} \text{ (inwards).}$$

$\dfrac{d^2r}{dt^2}$ is a deceleration which approaches 0 as r approaches r_f. It therefore starts negative. (Its proper sign is negative to make $\dfrac{\lambda^2}{r^3}$ positive).

(3) *See* (2). u_0 is only $=0$ if $v=\dfrac{\lambda^2}{\mu}$.

Equation of the Orbit. This is upset by putting $u=0$ when $r=r_0$. In that case, we have the original circular orbit.

(4) If the general case is worked out, it will be found, I think, that for a given central body there cannot be two elliptical orbits which *touch* each other. They must intersect if they meet. One elliptical orbit can only be converted into another by a change of *radial* velocity.

It may well be that the spiral I used by way of illustration requires some other term, or perhaps b to vary with θ, in order to be a possible natural orbit.

Graduates' and Students' Section

Harwell Visited

THE ATOMIC RESEARCH establishment at Harwell was visited on Saturday, 17th August. During three hours packed with interest we saw a fascinating cross-section of the work carried out there.

The visit began with a background briefing in the attractive new Cockcroft Hall and the showing of a short film. Thereafter the party divided into three groups and went to see the BEPO reactor, the handling of radio-active isotopes and the radio-chemistry block.

Harwell is the main establishment in the research group of the U.K. Atomic Energy Authority. The other main divisions of the U.K.A.E.A. are the industrial group, responsible for large-scale production operations, and the weapons group, which centres on Aldermaston.

Work at Harwell is concerned with research and design data for atomic and thermo-nuclear power generation, shielding and propulsion studies for submarines and tankers, isotope production, fundamental research with such apparatus as particle accelerators, radio chemistry, medical research, and so on. There are sixteen divisions, under the control of the director, Sir John Cockcroft.

At Harwell there are a series of research reactors, with cryptic names such as BEPO, DIDO, GLEEP, PLUTO, LIDO and ZEPHYR. We saw BEPO—British Experimental Pile—which went into service in July 1948.

A natural-uranium gas-cooled reactor, BEPO is graphite moderated. Its core is shielded by steel sheeting and six feet of concrete. BEPO was used for much of the work which led up to the Calder Hall reactors and those to be used in the new British atomic power stations. Today it produces radio-active isotopes and with it much experimental work is done, in particular studies in reactor technology.

Loop circuits through BEPO enable the working of projected reactors to be simulated. Those we saw represented reactors cooled by pressurised water, by organic liquid and by molten sodium respectively.

Radio-active isotopes are formed by subjecting compounds to radiation in the BEPO and DIDO reactors. A continuous belt in BEPO enables some isotopes to be produced without shutting the reactor down for their removal.

Isotopes are carefully handled; some are packed by remote control behind shielding walls of lead bricks. Isotopes produced at Harwell are distributed on a world-wide basis, carefully packed to avoid radiation hazards in transit. This can be done by enclosing small lead containers of isotope in large wooden cases; protection is achieved because radiation intensity decreases inversely as the square of distance from a source. Smaller cases of solid lead could be used, but these would be formidably heavy, particularly for air transport.

Radio-active treatment of materials is a new field with a vast scope. It enables such food as potatoes, meat and fruit to be sterilised so that its storage life can be prolonged. It also enables the physical properties of materials to be changed. Rubber, for example, can be vulcanised by irradiation. The potentialities of this technique are very great.

The third section of Harwell we visited was the radio-chemistry block. It is divided into two sections dealing with α and β radiation respectively.

Elaborate precautions are taken in dealing with radio-active material. All laboratories are equipped with special monitoring devices so that hands, feet and clothing can be examined for radio activity. In these monitors even the luminous dial of a watch produces an alarming series of clicks indicative of radiation. Special clothing is worn; even our party, although only on a tour, had to don special overshoes and coats.

All work with plutonium is carried out remotely and intricate and ingenious arrangements are made for this to be done. Handling is in special protective boxes called "glove" boxes, through which gloved hands can work.

The complicated engineering services of this block are on the windowless upper floor. All laboratories are air-conditioned and have fixed windows. Working chambers are maintained at a lower pressure than the laboratories so that any leakage can only be inwards. The services supply compressed air, steam, inert gases, etc., to the laboratories. On this floor a maze of ducts and piping, colour-keyed and looking like an orderly rainbow, indicates the complexity of the tasks carried out.

Our visit, although only short, gave us a graphic idea of the vast effort Britain is putting into atomic development. The cost, complexity and achievement of what we saw, although only a very small part of the whole, was most impressive—700 short words cannot begin to do it justice.

Our thanks go to the members of Harwell who so ably explained what we saw of their establishment and who always had the answers to our somewhat over-awed questions. It is most refreshing to go on a visit with guides who are obviously experts; the reverse is so often the case.
—J. R. COWNIE.

Lectures to Attend

The Under Secretary of State for Air, Mr. Charles Orr-Ewing, will give the first lecture of our autumn programme. He will speak about "The Future of the Royal Air Force," and his lecture will be at 7.30 p.m. on Thursday, 26th September, at 4 Hamilton Place.

It is hoped that as many of our members as possible will come to hear this authoritative lecture. The future role of the R.A.F. is of the greatest importance both to our national security and to the Aircraft Industry. The 1957 Defence White Paper has indicated the radical changes which face the R.A.F. today; these will be discussed by Mr. Orr-Ewing.

Our second lecture, on Wednesday, 16th October, will be by Mr. P. W. Brooks, technical assistant to the Chairman of British European Airways. He will talk about "Trends in Air Transport."

Later lectures will be "The Background to Aircraft Specifications," by Mr. K. W. Clark of the Air Ministry, to be given on Thursday, 7th November, and "Flight-testing Procedures at Supersonic Speed," by Wing Cdr. R. P. Beamont, Flight Operations Manager of English Electric, on Wednesday, 27th November. In addition, there will be a film show on Tuesday, 10th December.

The Road Research Laboratory

We are to visit the Traffic and Safety Division of the Road Research Laboratory at Langley, Bucks., on the morning of Saturday, 19th October 1957.

Anyone who has been before, will tell you what an interesting place it is, with many clever gadgets and demonstrations to be seen. We will probably see their test car on the skid pad, which is a Continental model with very advanced wheel suspension, and the novel property of self-jacking when a wheel needs changing!

Those interested should write to the new Hon. Visits Secretary, Mr. R. Shepherd, 4 Heath Road, St Albans, Herts.

THE LIBRARY

Reviews

REALITIES OF SPACE TRAVEL. *Selected papers of the British Interplanetary Society. Edited by L. J. Carter. Putnam, London, 1957. 431 pp. Illustrated. 35s.*

This volume contains a selection of papers which have been presented to the British Interplanetary Society during the past six years or so, and provides a very convenient summary of the ideas, in connection with space travel, that have developed in recent years. The 24 chapters can be divided into two broad classes; those which are based mainly on well established knowledge or on practical experience, and those which are frankly of a speculative nature. In the former class are to be found the general principles of rocket performance, discussion of the effects of mass ratio and of aerodynamic heating on re-entry to the earth's atmosphere, and some descriptions of research facilities already in existence, such as the rocket range at Woomera. There are also two chapters dealing respectively with what is known, or guessed, about conditions on the moon and on the planet Mars. In the more speculative chapters, problems such as food supply and atmosphere control during a long journey are considered, as are also the aero-medical and biological problems of space fllght. There is much interesting speculation as to the possible effects of the weightless condition that will be experienced when a space-ship is in a free orbit. The most speculative parts are the discussions on the possible use of nuclear energy for propulsion, and the last chapter of all which deals with the ultimate possibility of interstellar, as distinct from interplanetary flight; indeed, these two topics rather belie the word "realities" in the title of the volume. Nevertheless, they make very interesting reading.

The general broad conclusions that may be drawn from the book seem to be that with propulsion by known chemical fluids it is possible to envisage the establishment of artificial satellites, and even journeys as far as the moon, especially if these can be started from a satellite station rather than from the earth's surface. A journey to Mars seems impossible, or nearly so, with existing fuels and must await more powerful propellants, such as atomic energy, before it could be accomplished without an exorbitant mass ratio. The difficult problems of rendezvous with a small artificial satellite and of the transfer of goods and persons from one vessel to another in the vacuum of space are not touched upon at all. The book should prove of wide interest and should raise many questions to intrigue the imaginative reader; for example, is it true that if a man undertook a long interstellar journey at a speed near that of light, he would return to find that his children were older than their father?—ERNEST F. RELF.

THE HELICOPTER. *J. Shapiro. Muller, London, 1957. 269 pp. Illustrated. 21s.*

This is a book for the general reader and is guaranteed to contain none of the mathematics so dear to helicopter engineers—there is, in fact, not a single formula in the book. The author's aim is to explain the how and why of the helicopter and to discuss its potentialities.

In his opening sentence Mr. Shapiro describes the helicopter as "the fulfilment of an ancient dream of humanity, the complete and final conquest of the air." Similarly, to many Edwardians, M. Bleriot's flying machine must have seemed a "complete and final conquest." We shall surely see a development in the helicopter comparable to the fifty years improvement in fixed wing aeroplanes.

The helicopter today has far too many defects to be regarded as finalised. To the operator its cruising speed is still far too close to that of the wind for regularity in operation and its cost and complexity are high. To the passenger the vibration and noise levels are also high and to the engineer there is clearly much progress to be made. Even in hovering flight the single rotor, shaft-driven helicopter needs a tail rotor and this results in control and stability complications. In forward flight the entirely differing operating conditions of the advancing and retreating blades add many aerodynamic and structural problems. As a result the conventional helicopter pays a heavy price for the ability to fly slowly.

Those who read Mr. Shapiro's descriptions of today's helicopters will be interested in the next developments—convertible aeroplanes, flying platforms, etc. At first glance the book deals with these intriguing machines. There are excellent photographs of two convertible aircraft and of the Hiller "Flying Platform" but the former are mentioned only in passing in the text and the latter not at all, as far as I could see. (Surely an index in a book of this kind is desirable?) The text and diagrams appear to have been completed by the author and the photographs added by the publisher, since there is no reference to them in the text.

Here, then, is a valuable description of the position reached in the helicopter art but I am not convinced that we have achieved "the complete and final conquest of the air."—A. H. YATES.

THE THEORY OF SUSPENSION BRIDGES. *Sir Alfred Pugsley. Edward Arnold, London, 1957. 136 pp. 42s.*

Most members of the Society will know of Sir Alfred's contributions to the aeronautical sciences; perhaps not so many are aware of his important contributions to the theory of suspension bridges. It may have been the wish of his publishers to acknowledge the author's two-fold activities when they decided to illustrate the dust-cover by sketches of the flow patterns over stalled and unstalled aerofoils; unfortunately the effect is to introduce an incongruous feature into an otherwise well-produced publication.

The author's expressed intention is to collect together all the existing theories of suspension bridge analysis and to "establish all these theories in their proper setting and to show their scientific relationships." From his own experience the reviewer can affirm that such a book is much needed, for hitherto the various theories have had to be culled laboriously from scattered and detached sources. The timing of the publication is fortunate, for the revival of interest in suspension bridges in this country must have been quickened by the sanctioning of the suspension bridge project for the Forth crossing.

Chapter I gives a most interesting and informative historical introduction; from which we are surprised to learn that the influence of weight on the stiffness of the suspension bridge was not appreciated until the middle of the 19th century. After a full treatment of the simple

cable in Chapters II and III, the various theories follow in chronological order of their development, starting with the Rankine theory (Chapter IV) and leading to the elastic theory and its application (Chapters V and VI) and finally to the deflection theory and its developments (Chapters VII, VIII, and IX). Chapter X gives a number of approximate methods of analysis useful for preliminary design, among which is the author's own method which is based on an analogy between the flexible horizontal girder suspended from a flexible cable system and that of an elastic beam upon an elastic foundation. The final two chapters are devoted to the oscillations of suspension bridges: Chapter XI describes methods of calculation of natural modes and frequencies while Chapter XII introduces the subject of wind-excited oscillations. It was these two chapters that the reviewer found to be least satisfactory. For an adequate presentation both of their subjects need a fuller treatment. Most surprisingly, no mention is made in Chapter XI of the methods developed in recent years at the National Physical Laboratory for calculating the natural frequencies, and which are so particularly useful when a torsionally stiff suspended structure is incorporated, as is done in nearly all modern designs.

The book should become a standard text for civil engineering students and research workers and, although in no sense a design handbook for suspension bridges, it will certainly fill a gap in the bookshelves of the bridge engineer.—C. SCRUTON.

THE ROLE OF AIR FREIGHT IN PHYSICAL DISTRIBUTION. *Howard T. Lewis, James W. Culliton and Jack D. Steele. Harvard Business School, Boston, Massachusetts. Bailey Brothers and Swinfen, London, 1956. 179 pp. $2.50.*

This valuable study by the Research Division of the Graduate School of Business Administration at Harvard will open up new fields of thought for many who already have a wide interest in aviation.

Its two parts consider in detail the characteristics of the air freight market and, by means of case studies, analyse the effect of air freighting on marketing and distribution.

The study is well presented and the fundamental concepts which are laid bare are carefully stated. Evidence is provided to show that the range of commodities that are susceptible to air freight is broader than those having high value and low weight. A technique of cost analysis for goods distribution by land or air is suggested which could become a useful tool of management. The examples given illustrate the conditions under which air freight will be chosen as a major means of transport.

While the investigations reported were confined to the United States, the lessons learnt and the cases cited could probably be applied in all the greater industrial areas of the world. Among the conclusions to be drawn from this study is that a greater effort is required on the part of carriers to give emphasis to the selling of air freight. "Better service" is interpreted too often only as "better passenger service." A plea for a fuller understanding of the true worth of speed in air freighting is made. Almost always some aspect of inventory and warehousing is involved and there is reported a significant relationship between the use of air freight and the quality of planning by the potential user. The essential meaning of this most readable report is well expressed in the quotation offered from Dupuit (1844):

> "The ultimate purpose of a means of transportation ought not to be to reduce the expenses of transportation but to reduce the expense of production."

—ALAN H. STRATFORD.

HANDBOOK OF SEMICONDUCTOR ELECTRONICS. *Edited by L. P. Hunter. McGraw-Hill, New York, 1956. 601 pp. Illustrated. 90s.*

This book is the result of a successful attempt to place all the various aspects and developments of this new branch of electronics under one cover. It has proved an enormous task necessitating thirteen contributors, each a specialist in different aspects of the semi-conductor field. It is a work of some 300,000 words and the attempt at completeness can be gauged by the fact that the bibliography contains more than 2,000 entries.

The book deals mainly with the semi-conductor components; transistors, diodes and photocells, and is split into four parts. Part I deals with the physical aspect of electron behaviour in semi-conductors but starts very effectively with a factual descriptive chapter on the brief construction and the characteristics of transistors. It is meant as a preliminary introduction and survey, and gives the reader the necessary mental picture before the theory can be tackled. The following chapters then deal with; the theory of electronic conduction in solids including the effects of impurities in semi-conductors, rectification in solids at barriers, transistor action and frequency response, and finally to conclude the theoretical side a section on photoconductivity and photovoltaic cells.

The second part of the book is entitled "technology," and is concerned with the construction and manufacture of the semi-conductor devices. It starts with the problems and methods of preparation, purification and crystal growing of Germanium and Silicon. Preparation and construction of junctions and metal contacts follow and then chapters on "sealing off" and construction design finish this part, which forms a comprehensive and completely independent manual in itself.

The third part, by far the most important, occupying more than half the book, deals with the design of the various circuits built around these devices. It almost seems as if every avenue where there has previously been an application for thermionic valves has been explored using semi-conductor devices. The range covered is too great to list, but a few of the important subjects are worth noting. Amplification plays an important part, including a.c. and d.c. amplifiers, at low and high frequency, feedback and noise. There are large sections on sinusoidal and non-sinusoidal oscillators and switching circuits. Of extreme importance are the sections on computing circuitry indicating the extent to which digital computers can be "transistorised."

Part IV is of special interest to the serious student and research worker dealing with analysis and laboratory measurement. It includes matrix methods of circuit analysis and graphical methods of dealing with non-linear characteristics. The measurement side deals with obtaining the parameters of both the operating characteristics of devices and the properties of materials.

Each of the twenty chapters concludes with relevant references and the book finishes with a complete bibliography and an author and subject index. Although the major contributions to this field are American, those of other countries have not been forgotten. Taken altogether it forms an excellent comprehensive manual which will become a standard reference.—J. C. WEST.

MECHANICS FOR ENGINEERS, STATICS AND DYNAMICS. *F. P. Beer and E. R. Johnston, Jnr. McGraw-Hill, London. 1957. 673 pp. Diagrams. 60s.*

This book is written for the standard courses taught in the sophomore years of university life in U.S.A., equivalent

in England to two years of the School VI form and the first year of a B.Sc.(Eng.) degree course. It is a book of 673 pages and weighs over 3 lb. but fortunately the parts on Statics and on Dynamics are published separately.

In both Statics and Dynamics the subjects are treated on traditional lines; particles and rigid bodies are considered separately and problems in three dimensions occur. In the Statics section graphical methods are prominent—for the resultant of coplanar forces by force polygon, and for the analysis of forces in two-dimensional jointed structures using Bow's notation. The principle of virtual work and stability of equilibrium receive careful treatment and in the deflection of transversely loaded beams the sign conventions for shear force and bending moment is clearly shown. Centroids of areas, axes and volumes are obtained by integration methods; as are their radii of gyration. Products of inertia and principle axes find a place too.

Where systems of units are discussed in Dynamics (from Newton's second law of motion) the preference of engineers for gravitational systems, whether non-metric or metric, is emphasised, but possible difficulty when very precise measurements are made is pointed out. In the rectilinear motion of a particle the equations $\Sigma F_x = ma$, $\Sigma F_y = 0$ are used. (This, in the reviewer's experience, is not the best form of presentation for the weaker student). Forces on particles of variable mass enable rocket problems to be dealt with. In plane motion of a rigid body under forces the method of dynamic equilibrium is preferred to the use of force equations in the motion of the mass centre and rotation about the mass centre. (The advantage of the use of "inertia vector" and "inertia couple" is not apparent). Where impulses on rigid bodies are considered the linear and angular momentum equations are couched in somewhat unfamiliar form with phrases such as "Syst. Momenta" and "Syst. Ent. Imp.$_{1\to 2}$." At the end there is a four-page section on gyroscopic motion.

The general impression is of painstaking treatment on orthodox lines. There are many words, many illustrations and worked problems. Answers are given to all the even numbered problems—and there are over 700! The statement on the jacket claims "an unusually vivid clear presentation of the fundamental principles of statics and dynamics." To one engaged for many years in teaching mathematics to engineering students in a college of London University the immensity of everything—words, illustrations, problems to be worked—brings misgivings that the British student will hardly see the wood for the trees. It is much too lengthy for a textbook and only of limited use for reference. The reviewer regrets that there are so few problems using symbols only.—A. J. HATLEY.

LIFE IN THE AIR FORCE TO-DAY. *Group Captain E. C. Kidd. Cassell, London, 1957. 237 pp. Illustrated. 10s. 6d.*

"A young man's guide to all branches of the Royal Air Force" is a sub-title which is no hackneyed phrase, for Group Captain Kidd has achieved something quite unusual in this book. He has put into a small volume a tremendous amount of up-to-date information on the Service written from personal experience (he was himself a Halton Apprentice) in a very friendly manner which should appeal both to recruit and to parent. The Foreword by Marshal of the R.A.F. Sir John Slessor is a rare example of the man at the top talking to the man at the bottom of the ladder in his own language and not in any way talking down to him. Although it is a recruiting book it is far from dry and is a useful source of information on a virile Service which is changing rapidly to keep in line with Scientific developments.—A.S.C.L.

FLUGLEHRE (*6th edition*). *Dr. Richard von Mises and K. Hohenemser. Springer, Berlin, 1957. 402 pp. Diagrams. (In German). DM25.50.*

The number of popular books on aviation is legion, and there are also numerous textbooks dealing with the various technical and scientific aspects of the subject. Only a few authors however have attempted to explain the basic physical and technical principles on which aircraft are designed, for the instruction of those who are technically educated but not aircraft designers or technicians. Among these few, the late Richard von Mises must rank very high indeed.

The present sixth edition of Mises' well-known work has been extensively re-written and re-edited by Mr. Hohenemser, who is himself an eminent rotorcraft expert and had already collaborated with the first author in re-issuing the fifth edition, which appeared in 1936. The extensive additions to our knowledge during the past 20 years have required the inclusion of several new chapters, on compressibility, supersonic flow, gas turbines, automatic control and others. A new section on aircraft economics has also been added.

This book is not a textbook, in the sense that studying it will not enable one to engage in aircraft design. Its almost complete lack of mathematical treatment of the subject would in itself ensure that; nor is it possible to treat the wide range of problems covered to any depth in a mere 400 pages. Its lucid style and firm restriction to essentials make it an excellent introduction to the science of flight for anybody connected with aviation.—E. PRIBRAM.

DIE LUFTFAHRER: GESCHICHTE, LUST UND ABENTEUER DES BALLONFLUGS. *H. Schmitthenner. Muller & Kiepenheuer, Bergen, 1956. 158 pp. Illustrated. 16s. 8d. (DM9.80). In German.*

This is a strange little book. It sets out to present the history, pleasure and adventure of balloon flight, and it does it quite effectively through some 60 illustrations—including a few dirigible incumabula—and a collection of contemporary quotations on many of the "classic" balloon flights, tied together by a running narrative ending with the author's own flight—well photographed—in the balloon Augusta VI from Augsburg. But the trouble with reproducing long contemporary extracts unaccompanied by a critical commentary is that old wives tales, myths and legends are apt to run along with the truth. So it is that Glaisher's celebrated account of his celebrated flight on 5th September 1862 is included, but with no comment to the effect that if the old gentleman ascended without oxygen to the height he said he did—36,000 feet—he would have been a dead duck, or rather an asphyxiated aeronaut to say nothing of poor Coxwell, the pilot.

The author also, somewhat irrelevantly, includes the history of would-be heavier-than-air craft up to the 18th century, but this reviewer forgives him this once as he reports a 17th century French aviator who leapt twice from St. Paul's Cathedral, London, breaking his neck at the second performance. If anyone can furnish further information about this to-me-unknown event, I should be most grateful.—C. H. GIBBS-SMITH.

BIBLIOGRAPHY ON IGNITION AND SPARK-IGNITION SYSTEMS. *George F. Blackburn. National Bureau of Standards Circular 580, issued 1st November 1956. 15 pp. 15 cents.*

This bibliography contains more than 425 references to books, papers, and reports on ignition and ignition apparatus in internal combustion engines. The material covered includes not only electric equipment for spark-ignition but also firing by means other than compression ignition.

FAMOUS FIGHTERS OF THE SECOND WORLD WAR. *William Green. Macdonald, London, 1957. 128 pp. Illustrated. 18s.*

William Green has been co-author of several excellent books on modern military aircraft sharing one thing in common—accuracy. The latest book is, however, his own effort supported by some of the best work yet produced in the fashionable tone-drawings by Gert Heumann. Nineteen fighters, single- and multi-engined, friendly and hostile, are described giving a clear picture of their operational development. The choice of types is not beyond criticism since at least one notable British fighter, the Defiant, is omitted. Errors of fact are commendably few, although not absent altogether despite the author's passion for accuracy.

The worst criticism of the text is that hardly any mention is made of squadron numbers (none at all in the numerous illustrations, some of which are most unusual). The part played by R.A.F. squadrons, for example, in developing the new types of aircraft as they appeared was quite considerable and the inclusion of the numbers of those units and their theatres of operations would have increased greatly the historical value of the book. It is, however, a very useful textbook on a strictly limited subject.—A.S.C.L.

DOCTORS IN THE AIR. *Wing Commander Robert Maycock. 136 pp. text. Index. Illustrated. Allen & Unwin. 15s. net.*

From this interesting book I turned to the Air Force List to see how many R.A.F. medical officers currently hold flying decorations. I found twelve serving regulars have the Air Force Cross, two with a Bar, four the George Medal, one the Distinguished Flying Cross—splendid confirmation of the work of doctors in the air. These do not include my old friend, Dr. J. P. Huins, now a Gloucestershire G.P., whose remarkable record in three R.A.F. branches includes service as a combat pilot in France and Italy in the R.F.C. and R.A.F. in the First World War, ending as a Lieutenant. Then he joined 605 (County of Warwick) A.A.F. Squadron as a pilot when it was formed, and later became its M.O. with the rank of Flight Lieut. In the Second World War he was attached to H.Q. Bomber Command, and there gained the A.F.C. and Bar and the O.B.E. for his work as the Command's flying doctor. Today he is a Sqdn. Ldr. in the Medical Branch of the R.A.F.V.R.

All these decorated doctors appear in Wing. Cdr. Maycock's story, but not all are mentioned by name, which I think is a pity, for their work deserves more than anonymity. Yet many are mentioned in this excellent account of their thrilling work, which carries us from mythological times to the present day. Both then in fabled story and since in recent times flying doctors have given their lives in quest of empirical knowledge.

Captain Lithgow and Staff-Surgeon Wells were the two M.Os. appointed to the original Royal Flying Corps in 1912. Both learned to fly in 1913. In the First World War Graeme Anderson was the great flying doctor in the R.N.A.S., while Martin Flack shone in the R.F.C. by instituting airfield research (with this I was connected as a flying instructor) from which he founded the first scientific medical assessment of aspirant pilots. Flack invented the test of blowing and holding the mercury in the U-tube to 40 mm. while the candidate's blood pressure is measured.

Between the wars, medical flight research was slow, But since the Second World War began, it has leapt ahead under the name of aviation medicine. In wartime, many R.A.F. M.Os. qualified as pilots and flew in operations to study combat conditions—hence the D.F.C. Today, many fly jets. As flying "guinea-pigs" they have personally tested medical theories about anoxia, high manoeuvre loadings, parachute escape (including free fall delayed opening and power jettisoning), low temperature exposure during flight and in rubber dinghies, decompression fatigue both in the chamber and at high altitude, and have flown overlong hours (*e.g.* in the Berlin Airlift) to assess flying strain on pilots and define wise regulations to prevent it. (Himself a doctor-pilot, Maycock describes all this well, in his dramatic and non-technical story.) Through this physiological occupational quest efficient oxygen equipment, pressure suits and cabins, anti-*g* and anti-sweat suits, improved night vision, and organised casualty air evacuation have been evolved. Those who do not know this side of aviation should read this book. Its few errors in the early history of British aviation are unimportant and irrelevant, yet irritating to readers who know otherwise, and they should be corrected in the first reprint.—NORMAN MACMILLAN.

WEATHER MAP. *Meteorological Office. H.M.S.O., London, 1956. 104 pp. Illustrated. 10s. 6d.*

This latest (4th) edition of a book first published 40 years ago, gives greater attention than before to the causes of our most frequently experienced weather phenomena. A new set of weather maps in the up-to-date manner and showing typical pressure distribution has been included, and modern forecasting techniques are described. Selected actual forecasts are discussed in relation to the surface and upper air maps on which they are based, with indications of the considerations which led the forecaster to his conclusions.

The book is very readable, being written in a style appropriate to the intelligent, but meteorologically uninstructed, general public to whom it is primarily directed.

WORLD AVIATION DIRECTORY. *Spring-Summer 1957. American Aviation Publications. 988 pp. $10.*

It is really rather difficult to find something new to say about these publications that come along once, twice or more each year. Each has its own particular sphere of usefulness and all are more or less "musts" for the aeronautical bookshelf if it is to be complete. American Aviation (World Wide) Directory has very kindly changed its title to World Aviation Directory, thus giving one something new to say and making for slight confusion in some minds until they are attuned to the new title. The Directory is also nearly 100 pages longer than the previous edition thus helping to justify its cost to sceptical accountants. There can be no doubt that to anybody with international aeronautical interests the Directory is invaluable with its coverage of officialdom, industry, individuals and the rest.—F.H.S.

MY FIFTY YEARS IN FLYING. *Harry Harper. Associated Newspapers 1956. 256 pp. Illustrated. 12s. 6d.*

The author got in on the ground floor of aviation in this country when he was appointed the first of a long line of "special air correspondents" by his newspaper. One would, therefore, have expected an exciting book of reminiscence but we have, instead, what looks like a series of newspaper columns. One has read so much of the material before and little has been done to give a "fresh slant" to old stuff. Although Mr. Harper inevitably knew all the pioneers intimately one gets no personal touch. In one story he does make the reader almost breathless

with excitement and that is in his description of the London-Manchester air race. The trouble is, of course, that we already know the result.

I think he should not describe himself as a historian. With the examples of historical writing and research that appear in this Journal and others, such a claim appears presumptuous.—F.H.S.

THE WORLD'S FIGHTING PLANES. *2nd completely revised edition. W. Green and G. Pollinger. Macdonald, 1956. 248 pp. 15s.*

A work with a title like this must inevitably be revised from time to time and in these specialised times a book which deals with the essential details of a specialised branch of aeronautics is a useful reference tool. There is the point, of course, that all the details can be found elsewhere but Messrs Green and Pollinger kindly collect all the material they can about fighter and bomber aircraft and put them under one roof—nicely divided into countries of origin and alphabetically indexed. In their foreword, the authors imply that the upper limit in bomber size has been reached. Any writer on aeronautics who makes any sort of prophesy at all has the chance of being dubbed, in five years' time, (*a*) a damned fool (*b*) a clever prescient bloke. Take your pick.—F.H.S.

LITERATURVERZEICHNIS DER ASTRONAUTIK. *H. H. Koelle and H. J. Kaeppeler. Published by Walter Pustet, Oberbayern, 1954. 6.40 Dm.*

Should there, at this date, be any Doubting Thomases who feel that there is no future in Astronautics, they should obtain a copy of this little book.

It is an excellently produced guide to the literature of the subject and gives, besides, 2¾ pages of journals and periodicals which deal with astronautics either directly or as a fringe subject (including the Journal of the Royal Aeronautical Society), a list of abbreviations, a subject classification and an author index. In addition, it is in German *and* English.—F.H.S.

AERONAUTICAL ENGINEERING CATALOG 1957. *Institute of the Aeronautical Sciences Inc., 1957. 358 pp. Illustrations. $7.50.*

The Aeronautical Purchasing Officer in the United States is particularly well served. At least two of their periodicals issue separate Buyers' Guide numbers each year and the I.A.S. produces its lavish "catalog."

With American firms building up connections in this country, this volume could well be a worthwhile addition to any aircraft manufacturer's buying department.

Although it is customary to denigrate our own productions, if you take away the glossy advertisements, the "catalog" is a kind of "Sell's British Aviation"—but probably not so comprehensive.—F.H.S.

THE AIRCRAFT YEAR BOOK 1956. *Aircraft Industries Association of America Inc. Lincoln Press Inc., 1957. 484 pp. Illustrations. $6.00.*

While America has nothing quite like "Jane's" I do not think this country has anything quite like the Aircraft Industries Association's "Aircraft Year Book."

The 38th annual edition (1956) follows the previous patterns and reviews the year's progress in American Aeronautics. The chronology of U.S. aviation is brought up to 27th November 1956 and there are the usual impressive photographs of "Planes in Production." How much easier would the information officer's lot be had this annual started in 1903!—F.H.S.

Additions to the Library

Abbott, A. F. and Nelkon, M. ELEMENTARY PHYSICS, BOOKS 1 AND 2. Heinemann. 1957. 7s. 6d. each.

Curtis, E. P. AVIATION FACILITIES PLANNING (A REPORT BY THE PRESIDENT'S SPECIAL ASSISTANT). U.S.G.P.O. 1957. 25c.

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*National Advisory Committee for Aeronautics. FORTY FIRST ANNUAL REPORT OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS 1955. U.S.G.P.O. 1957. 9 dollars.

National Physical Laboratory. MODERN COMPUTING METHODS. (NOTES ON APPLIED SCIENCE NO. 16.) H.M.S.O. 1957. 10s. 6d.

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O.N.E.R.A. COMPTES RENDUS DES JOURNÉES INTERNATIONALES DE SCIENCES AERONAUTIQUES, 1er. partie. O.N.E.R.A. 1957.

Scheidegger, A. E. THE PHYSICS OF FLOW THROUGH POROUS MEDIA. University of Toronto Press. 1957. 110s.

Scott Bader Co. Ltd. POLYESTER HANDBOOK. 1957.

Stewart, *Col.* J. D. (*Editor*). AIRPOWER: THE DECISIVE FORCE IN KOREA. van Nostrand. 1957. 45s.

Sutton, O. G. THE SCIENCE OF FLIGHT. (REVISED EDITION.) Penguin. 1955. 3s. 6d.

Williams, B. and Epstein, S. THE ROCKET PIONEERS. Lutterworth Press. 1957. 15s.

Z.L.D. VERZEICHNIS FRÜHEREN DEUTSCHEN LUFTFAHRTSCHRIFTTUMS, etc. Z.L.D. Munich. 1957.

* *Items marked thus are for reference only.*

Reports

AERODYNAMICS

BOUNDARY LAYER—*see also* THERMO-AERODYNAMICS

Local coefficients of skin friction and heat transfer for turbulent boundary layers in two-dimensional diffusers. J. N. Hool. R. & M. 2986. 1957.—(1.1.3 × 1.9.1).

Effect of yaw on the compressible laminar boundary layer. J. Tinkler. R. & M. 3005. 1957.

The equations governing the laminar compressible boundary layer on a yawed body of infinite span are transformed to give three non-dimensional equations defining two velocity components and the enthalpy. Assuming that the Prandtl number is unity and that there is zero heat transfer, a relation is obtained between the stream Mach number and the angle of yaw for flows which give the same boundary layer equation. The further assumption of viscosity proportional to the absolute temperature is made and "similar" solutions are found to be given by a family of surface Mach number distributions normal to the leading edge. "Similar" solutions, obtained from a differential analyser, are presented for a range of two controlling parameters.—(1.1.1).

The three-dimensional boundary-layer equations and some power series solutions. L. C. Squire. R. & M. 3006. 1957.

The boundary layer equations are derived for a very general co-ordinate system, and various theorems hitherto only proved in more restrictive systems are extended to this general system. The particular case of streamlines of zero geodesic curvature is investigated in detail and a solution of such a flow found by a power series method. Finally Howarth's stagnation-point solution is extended to second-order terms by numerical investigation.—(1.1.1.1)

*A simplified method for the calculation of three-dimensional laminar boundary layers. J. A. Zaat. N.L.L. Report F.*184. *April* 1956.

By aid of the assumption that the boundary layer velocities in the direction perpendicular to the local free flow are small compared with those in the direction parallel to this flow, it is possible to approximate the momentum equations for three-dimensional laminar boundary layers by two total differential equations of the first order. The boundary layer quantities in the direction of the local free flow are calculated by neglecting the boundary layer cross flow but taking into account the three-dimensional character of the potential flow. This only requires the evaluation of an integral. Thereafter, the cross flow is calculated by using the results for the main flow, which leads to an integral equation. The simplified method has been applied to the flow about a yawed ellipsoid at zero incidence. The results agree very well with those obtained from the complete momentum equations.—(1.1.1.1).

Similar solutions for the compressible laminar boundary layer with heat transfer and pressure gradient. C. B. Cohen and E. Reshotko. N.A.C.A. Report 1293. 1956.

Stewartson's equations for the compressible laminar boundary layer with pressure gradient and heat transfer are solved for pressure gradients varying from that causing separation to the infinitely favourable gradient, and for wall temperatures from absolute zero to twice the free-stream stagnation temperature.—(1.1.1.4 × 1.9.1).

The compressible laminar boundary layer with heat transfer and arbitrary pressure gradient. C. B. Cohen and E. Reshotko. N.A.C.A. Report 1294. 1956.

An approximate method for the calculation of the compressible laminar boundary layer with heat transfer and arbitrary pressure gradient, based on Thwaites' correlation concept, is presented.—(1.1.1.4 × 1.9.1).

COMPRESSIBLE FLOW—*see also* WINGS AND AEROFOILS TESTING AND INSTRUMENTS

Tables of various Mach number functions for specific-heat ratios from 1·28 *to* 1·38 *Lewis Laboratory Computing Staff. N.A.C.A. T.N.* 3981. *April* 1957.

Tables of Mach number functions are presented for a range of specific-heat ratios. The tables provide information supplemental to the notes and tables of Report 1135.—(1.2).

Interaction of moving shocks and hot layers. R. V. Hess. N.A.C.A. T.N. 4002. *May* 1957.

Interactions are treated of normal and oblique shocks with hot layers at various temperatures. A brief discussion of spherical and cylindrical shocks is also given. Emphasis is on the fact that at very high temperatures the hot-layer shape undergoes drastic changes.—(1.2.3.2 × 1.9).

CONTROL SURFACES—*see also* TESTING AND INSTRUMENTS

R.A.E. high-speed wind-tunnel tests of the trailing-edge controls on a delta wing with 52-deg sweepback. K. W. Newby. R. & M. 2999. 1957

Tests have been made in the Royal Aircraft Establishment 10 ft. × 7 ft. High-Speed Wind Tunnel to determine the effectiveness of trailing edge controls on a delta wing of 52° leading edge sweep and N.A.C.A. 0010 section (trailing edge angle 12°) using the half-model technique. Three plain controls were tested—an inboard control, an outboard control, and the two combined.—(1.3).

INTERNAL FLOW

Heat transfer to turbine blades. S. J. Andrews and P. C. Bradley. C.P. 294. 1957.

Before the design of cooled turbines, a knowledge of the heat transfer coefficients to turbine blades is required. The results of tests on two typical cascades, together with some other collected results, are here reported.—(1.5.3.2).

Tunnel-wall effect on an aerofoil at subsonic speeds. A. Thom and L. Klanfer. R. & M. 2851. 1957.

The effect of the presence of walls on the flow past a symmetrical aerofoil at zero incidence is discussed. The low-speed case is considered first, followed by solutions at a Mach number of 0·7. The methods used are essentially arithmetical, but a new approach is used for the compressible case. The manner in which the walls affect the pressure distribution is clearly shown.—(1.5.1.4 × 1.10.1).

The component pressure losses in combustion chambers. H. A. Knight and R. B. Walker. R. & M. 2987. 1957.

The available knowledge of the component losses in a combustion chamber is summarised. The information given should enable the pressure drops through swirlers, primary baffles, cooling systems, etc., to be calculated. In certain cases (*e.g.* mixing losses) the information is incomplete and in these circumstances the limited experimental results available are supplemented by hypotheses which require proof. A specimen calculation of the pressure drop and airflow distribution of a typical chamber is given.—(1.5 × 27).

An investigation of the high alternating stresses in the blades of an axial-flow compressor. J. R. Forshaw. R. & M. 2988. 1957.

A vibration investigation of the 1st, 2nd and 3rd stage stator of an axial flow compressor is reported. Excessive values of the alternating stress were obtained, and for some of the maxima the incidence was estimated to equal the stalling incidence. There is excitation at all speeds of low orders showing dissimilar flow in different parts of the stage and this excitation increases in a critical manner at or near stalling incidence indicating a partial stall which is localised in parts of the stage. At greater incidence the flow

NOTE.—*The figures in parenthesis at the end of each Summary are for office use only.*

deteriorates, the contrast between various parts of the stage is reduced, and the level of the alternating stress falls to a value slightly higher than that at incidences lower than the partial stall. This phenomenon occurs for critical operating conditions and is different from stalling flutter. Both phenomena could occur in the same compressor, the latter would be influenced by blade stiffness and could occur over wide ranges of operation.—(1.5.2.1).

Wall interference in a perforated wind tunnel. R. Brescia. N.A.C.A. T.M. 1429. *May* 1957.

The interference of perforated walls on sources and doublets is treated by showing that as the dimensions of a cascade wall become small, the cascade wall approximates a vortex sheet. Special singularities called "reflected" and "transmitted" are developed to simulate the interference of the vortex sheet on the original singularities. Equations are given for the interference of two perforated walls on the flow fields of two-dimensional sources and doublets.—(1.5.1.4).

Charts for the analysis of flow in a whirling duct. R. A. Makofski. N.A.C.A. T.N. 3950. *May* 1957.

Charts are developed for the analysis of flow in a whirling constant diameter duct. These charts permit the determination of the duct exit Mach number, or the Mach number at any point along the duct, for practical ranges of duct inlet Mach number, duct-tip Mach number, friction factor, ratio of ambient temperature to duct flow total temperature, ratio of duct-tip radius to duct hydraulic diameter, and heat conductivity through the duct wall and surrounding material. The method of using the charts is illustrated through the computation of a sample problem.—(1.5.1).

Cascade investigation of a related series of 6-percent-thick guide-vane profiles and design charts. J. C. Dunavant. N.A.C.A. T.N. 3959. *May* 1957.

A new guide vane blade series for high critical speeds of improved section characteristics has been derived. Low-speed cascade tests were made of four blade sections of this series at solidities of 0·75, 1·00, and 1·50. From these tests, design angles of attack were selected and are presented as a method of determining camber for guide vane turning angles as high as 50°. The results of a number of simple computations made to estimate the high-speed characteristics of the blade series are presented.—(1.5.4.2).

LOADS

Theoretical load distributions on fin-body-tailplane arrangements in a side-wind. J. Weber and A. C. Hawk. R. & M. 2992. 1957.

A theory has been developed for calculating the distributions of side force and lift on fin fuselage-tailplane arrangements in a side-wind but with the tailplane set at zero incidence. The analysis is limited to incompressible flow and has been further simplified by assuming that the geometrical arrangement is in each case such as to give constant induced sidewash. The results, which can be extended to other arrangements and to compressible subcritical flow, are required for stability and stressing analysis.—(1.6.1 × 1.8.1).

STABILITY AND CONTROL—*see also* LOADS

The aerodynamic derivatives with respect to a rate of yaw for a delta wing with dihedral and at incidence at supersonic speeds. J. H. Hunter-Tod. R. & M. 2887. 1957.

Expressions are developed on the basis of an unsteady flow analysis for the yawing derivatives for a delta wing with small dihedral at small incidence flying at supersonic speeds. The assumptions of the linearised theory of flow are made throughout; only first-order terms in the rate of turn are considered.—(1.8.1.2).

Problems of longitudinal stability below minimum drag speed, and theory of stability under constraint. S. Neumark. R. & M. 2983. 1957.

Reasoning proposed in 1910 purported that flight below minimum drag speed should be fundamentally unstable, so that any speed error would lead to a divergence. This reasoning is shown to be invalid on the ground of the general theory of dynamic stability in uncontrolled flight, the criterion being a grossly inadequate approximation to the condition of phugoid stability. However, the criterion may be fully vindicated for the case of flight controlled by the elevator in such a way as to maintain constant height. The criterion also applies to the problem of ultimate height response to an elevator deflection. The concept of stability of partially controlled flight is further developed, leading to a general theory of "stability with constraint," *i.e.* when a control (elevator, throttle, and so on) is used to suppress one component of the disturbance.—(1.8.2.1).

Notes on correlation of model and full-scale spin and recovery characteristics. M. N. Gough. AGARD Report 27. *February* 1957.

The usefulness of spin tunnel results as an aid to piloting techniques in flight operations is calculated. A correlation of spin tunnel and flight test results is presented. Included are notes to pilots emphasising the value and limitations of existing spin tunnel information.—(1.8.3).

THERMO-AERODYNAMICS—*see also* BOUNDARY LAYER *and* COMPRESSIBLE FLOW

A note on the effect of heat transfer on peak pressure rise acssociated with separation of turbulent boundary layer on a body of revolution (N.A.C.A. RM-10) at a Mach number of 1·61. *K. R. Czarnecki and A. R. Sinclair. N.A.C.A. T.N.* 3997. *April* 1957.

The effects of heat transfer on the peak pressure rise associated with the separation of a turbulent boundary layer on a body of revolution (N.A.C.A. RM-10) at a Mach number of 1·61 have been determined experimentally. Tests were made over a Reynolds number range, based on the distance from model nose to separation point, from $11{\cdot}6 \times 10^6$ to $34{\cdot}8 \times 10^6$ for a ratio of model-wall temperature to stagnation temperature of 0·96 (zero heat transfer) to 0·75.—(1·9·1 × 1·1.4.4).

WINGS AND AEROFOILS—*see also* INTERNAL FLOW *and* AEROELASTICITY

Lift, drag, and pitching-moment characteristics of AGARD calibration models A and B at Mach numbers 3·98 *to* 4·98. *C. J. Schueler. ASTIA Doc. No. AD*-123507. *May* 1957.

Lift, drag, and pitching-moment characteristics of AGARD calibration models A and B have been determined in a 12 in. supersonic wind tunnel. Model A was tested over a Reynolds number range from $1{\cdot}4 \times 10^6$ to $6{\cdot}8 \times 10^6$ and model B over a Reynolds number range of $1{\cdot}0 \times 10^6$ to $4{\cdot}6 \times 10^6$, based on body length.—(1.10.2.2 × 1.2.3).

A special method for finding body distortions that reduce the wave drag of wing and body combinations at supersonic speeds. H. Lomax and M. A. Heaslet. N.A.C.A. Report 1282. 1956.

For a given wing and supersonic Mach number, the problem of shaping an adjoining fuselage so that the combination will have a low wave drag is considered. Only fuselages that can be simulated by singularities (multipoles) distributed along the body axis are studied.—(1.10.1.2 × 1.2.3).

Lift and moment responses to penetration of sharp-edged traveling gusts, with application to penetration of weak blast waves. J. A. Drischler and F. W. Diederich. N.A.C.A. T.N. 3956. *May* 1957.

The lift moment responses to penetration of sharp-edged travelling gusts are calculated for wings in incompressible and supersonic two-dimensional flow, and for very narrow delta wings. By using the two-dimensional indicial lift functions, some calculations of normal acceleration response are made for two mass ratios. The relation between gusts travelling at supersonic speeds and blast waves is indicated.—(1.10.1.2 × 2).

TESTING AND INSTRUMENTS

On the choice of the working fluid for intermittent supersonic wind tunnels. G. A. Bird and G. M. Lilley. CoA Report 112. *January* 1957.

The general advantages and disadvantages of using a gas other than air as the working fluid in a wind tunnel are

discussed. A number of gases and gas mixtures (in particular, air, Freon 12, helium and Freon 12-Argon) are compared on the basis of their Reynolds number against Mach number characteristics when expanded from given stagnation conditions and the limitations, which are imposed on the maximum Mach number by the condensation of the gas, are calculated. The size and complexity of the required pressure vessels and associated equipment is discussed for the different gases and some conclusions are reached as to the more suitable gases for various ranges.—(1.12.1.3).

The measurement of high frequency alternating pressures in gas turbines. J. R. Forshaw and H. Taylor. R. & M. 2990. 1957.

Improvements were required in the recording techniques which are reported elsewhere but the changes in amplifiers are described. The development of a capacity pressure elements to record the alternating pressures at a point in a casing is described.—(1.12.5).

Loads on a model during starting and stopping of an intermittent supersonic wind tunnel. K. G. Winter and C. S. Brown. C.P. 335. 1957.

Measurements are given of the loads on a model during starting and stopping of an intermittent supersonic wind tunnel at Mach numbers of 2·00 and 2·48. The use of a model loading coefficient in terms of tunnel stagnation pressure is proposed.—(1.12.1.3).

Brief description of the R.A.E. intermittent supersonic wind tunnel plant. K. G. Winter. C.P. 336. 1957.

The plant is vacuum-operated on a closed circuit with with storage of the air in a flexible container. The useful Mach number range is up to about 4·5. For the largest of the tunnels (15 in. × 16 in.) the maximum running time is of the order of 20 seconds over the whole Mach number range. Runs of 10 to 15 seconds duration can be made every 5 minutes.—(1.12.1.3).

Tables of characteristic slopes for use in the design of nozzles for supersonic wind tunnels. K. G. Winter. C.P. 337. 1957.

Tables are given which are of use in the calculation of characteristic networks appropriate to two-dimensional nozzles for Mach numbers up to 4·5. The tabulated characteristics slopes enables the co-ordinates of a characteristic intersection each to be evaluated in one operation on a desk calculating machine.—(1.12.1.3 × 1.2.3.)

Some comments on high-lift testing in wind tunnels with particular reference to jet-blowing models. A. Anscombe and J. Williams. AGARD Report 63. *August* 1956.

Some of the special problems of wind tunnel testing which arise in high-lift work are considered. Discussion is confined to current experience in the R.A.E. and N.P.L. low-speed wind tunnels, and refers mainly to tests on blowing over flaps or jet flaps. Comments are made on suitable size of model, methods of feeding compressed air into models without affecting balance readings, and general test technique. Methods of model construction are not specifically discussed.—(1.12.1.1 × 1.3.4).

Note on strain gauge recording equipment for the R.A.E. intermittent supersonic wind tunnels. K. G. Winter and E. J. Petherick. AGARD Report 64. *August* 1956.

A description is given of a simple system for photographing, up to six times per second, revolution counters driven from strain gauge balance indicators. A further proposed system using punched cards is also described.—(1.12.6.2).

La rénovation de la soufflerie S3 du Service Technique Aéronautique. R. Lecardonnel. Pub. Sc. et Tech. B.S.T. 119. 1957.

Amélioration des qualités d'écoulement du courant d'air. Etude et installation d'une chambre de tranquillisation et d'un filtre. Etude et installations de filets stabilisateurs. Augmentation de la vitesse d'essais. Etude et installation d'un récupérateur arrière. Calcul complet (aérodynamique et mécanique) d'un nouveau ventilateur. En annexe, méthode simplifiée de calcul aérodynamique d'un ventilateur de soufflerie.—(1.12.1.1).

AEROELASTICITY

See also STRUCTURES—THEORY AND ANALYSIS

Flutter calculations on a supersonic aircraft wing. Ll. T. Niblett. C.P. 328. 1957.

Flutter calculations have been made on a straight-tapered unswept wing of low aspect ratio both with and without engines to discover the stiffness necessary to avoid flutter up to a Mach number of 2 and to find whether wing engines can be used to massbalance the wing effectively. Simple arbitrary modes of flexure and torsion were assumed and calculations were made using subsonic, transonic and supersonic derivatives.—(2).

Wind tunnel flutter tests on a delta wing with an all-moving tip control surface. D. R. Gaukroger. R. & M. 2978. 1956.

Wind tunnel tests on a half-span model delta wing, fitted with an all-moving tip control surface, are described. The model is flexible and the control is rigid. Provision is made for varying the circuit stiffness and the position of the centre of gravity of the control surface and its pitching moment of inertia. The tests show that certain combinations of control-surface inertia and circuit stiffness produce very low flutter speeds. The effect of reducing the control-surface area by cropping the tip is examined, and in general is found to be beneficial. It is shown that the most favourable conditions for avoiding low flutter speeds exist when the control-surface centre of gravity is well forward of the hinge-line and the control-surface natural frequency is well removed from the natural frequency of the wing in its fundamental flexural mode—(2 × 1.10.2.2).

DESIGN AND CONSTRUCTION

Model selection and design practices applicable to the development of specific aircraft. D. D. Baals. AGARD Report 21. *February* 1956.

Factors pertinent to a specific model development programme are discussed together with the major aerodynamic and mechanical requirements of model design. Airframe aerodynamic problems, including the influence of inlets, are considered, but the internal aerodynamics of the engine proper are excluded. Five basic development and five special purpose models are discussed as the typical array necessary for the development of a present-day supersonic fighter.—(4).

Ground simulator studies of the effects of valve friction, stick friction, flexibility, and backlash on power control system quality. B. P. Brown. N.A.C.A. T.N. 3998. *April* 1957.

Ground simulator tests were made to study the effects of various ratios of valve friction to stick friction on power control system quality. Boundaries are determined for good, tolerable, and unsatisfactory ranges of valve and stick friction for a rigid control system and a system with flexibility between the source of stick friction and the valve. The effect of various friction ratios with flexibility between the pilot and the source of stick friction is presented. The effect of backlash with various friction ratios is also presented.—(4.3).

AIRCRAFT OPERATION

Philosophy of airworthiness. W. Tye. AGARD Report 58. *August* 1956.

The matching of airworthiness of the aircraft with the external operational conditions is discussed. The difficulty of establishing what level of airworthiness is acceptable to the community is pointed out, and a possible way of attacking the problem is suggested. Preliminary examination indicates that there is an optimum level of airworthiness. A distinction is drawn between the "accident rate" and "accident probability" approaches to airworthiness, and the moral and technical implications of these are discussed. The present state of certain important structural requirements is examined in the light of the preceding general considerations. The main weaknesses in the current requirements are underlined. Brief reference is made to the problem of airframe fatigue.—(5.3).